Samuel Dana Greene

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Constitution, Article VII, Sec. 2.

TRANSACTIONS

OF THE

AMERICAN INSTITUTE OF ELECTRICAL ENGINEERS.

Vol. XVI. JANUARY TO DECEMBER. 1899.

New York, January 25th, 1899.

The 131st meeting of the INSTITUTE was held this date at 12 West 31st Street, and was called to order by President Kennelly at 8 o'clock P. M.

The Secretary announced that at the meeting of the Executive Committee in the afternoon, the following associate members were elected:

Name.	Address.	Endorsed by
DAGGETT, ROYAL BRADFORD	Electrical Engineer, Electric Storage Battery Co., Marquette Building, Chicago, Ill.	Herbert Lloyd. J B. Entz. H. H. Wait.
DYER, ERNEST I.	Engineer and Manager of the Engineering Department of the American Trading Co., Box 28 Yokohama, Japan.	C. L. Cory. J. N. LeConte. J. A. Lighthipe.
HILL, GEO. HENRY	Chief Engineer, Elevator Department, Sprague Electric Co., Bloomfield, N. J.; residence, New York City.	F. J. Sprague. E R. Carichoff. Louis Duncan.
HILL, ERNEST ROWLAND	Electrical Engineer, Westinghouse E. & M. Co., Pittsburg, Pa.	C. F. Scott. L. B. Stillwell. Harris J. Ryan.
LYNN, WM. A.	Assistant in Electrical Engineering, University of California, Berkeley. Cal.	C. L. Cory. J. N. LeConte. F. V. T. Lee.
SIMPSON, J. MANLEY	Assistant Superintendent, North-Western Grass Twine Co., P. O. Box 2513, St. Paul, Minn.	F. A. C. Perrine. C. A. Carus-Wilson Ralph W. Pope.
THOMPSON, THOS. PERRIN	Electrical Laboratorian, Brooklyn Navy Yard; residence, 217 Cumberland St., Brooklyn, N. Y.	Townsend Wolcott Frederick Bedell. Harris J. Ryan.
THOMPSON, ALFRED J.	Electrical Engineer and Contractor, San Ignacio 50, Havana, Cuba.	Thos. A. Edison. A. E. Kennelly. Gano S. Dunn.
WILSON, ROBERT M.	Faculty of Applied Science, McGill University; residence, 113 Shuter Street, Montreal, Que.	R. B. Owens. R. A. Ross. Ralph W. Pope.

Total, 9.

The following Associate Members were transferred to membership.

Approved by Board of Examiners, December 9th, 1898.

PHILANDER BETTS, Electrician U. S. Navy Yard, Washington, D. C.
WINDEN ELWELL GOLDSBOROUGH, Professor of Electrical Engineering, Purdue University, Lafayette, Ind.

THE PRESIDENT:—In introducing the paper of the evening, I have the pleasure to announce that Mr. Greene himself is present and he has, as you know, been spending some months professionally in the navy. We shall look for an interesting paper at his hands upon "Electricity on Board Ship."

A paper presented at the 131st Meeting of the American Institute of Electrical Engineers, New York, January 25th, 1899, President Kennelly in the Chair.

ELECTRICITY ON BOARD SHIP.

BY S. DANA GREENE.

While the title of this paper is intended to cover the applications of electricity aboard ship in the merchant marine, as well as in the navy, I shall confine my remarks principally to the war vessel; for the service requirements of electrical apparatus on the latter are quite as severe as on the former, while the limiting conditions as to weight and space are much more severe. It may be safely assumed therefore that any application which can be made to advantage aboard a man-of-war will be equally advantageous on board a merchantman.

On shore, the advantages of centralizing the manufacture of electric power for industrial purposes in one plant, distributing this power by suitable means to individual consumers, are so well known, and the industry is so well established, that it seems hard to realize the fact that it has all been accomplished in less than twenty years, and that it is less than ten years since it was a difficult matter to interest capital in such undertakings. For several years after the industry was well established ashore, little or nothing was done aboard ship. This was due principally to two causes:

First: Seafaring men are notoriously conservative about introducing new ideas or new apparatus aboard ship, which may prove successful, and which may on the other hand fail in the middle of a long voyage when facilities for repairs are not at hand, and when a break-down may be a very serious matter to the safety of the ship, or the lives of the officers and crew. This conservatism is particularly strong in the British navy, the

greatest in the world, where no machinery is ever introduced when the work can be done as well by hand, and where simplicity is the first requirement for all machinery.

The modern warship is a complex piece of mechanism at best, and I think the established policy of our British cousins to eliminate rigidly all *unnecessary* complications is wise; one that can well be followed by other navies and particularly our own, where there has been a tendency to introduce too many novelties and labor-saving devices, at the expense of simplicity and safety.

Second: Electrical men, while generally unfamiliar with the conditions of sea life, knew nevertheless that three great enemies of electrical apparatus—salt air, moisture and heat—were always present aboard ship, and they feared them.

However, the great advantages of electric lights gradually overcame the sailor's conservatism and the electrician's fears, and lighting plants have been generally installed aboard ship for several years, in spite of numerous troubles at first, both with the apparatus and with the wiring.

The great advances made in the construction of electrical apparatus and the methods of distribution, enable us to say today, and to prove as I shall hope to prove, with a full knowledge of service conditions,—that electrical applications can be made with as little fear and with as great certainty of success aboard ship as they can ashore.

The recent position reported to have been taken by one of the Naval Bureau chiefs that such applications should not be further extended on our war-ships at present, because we did not have the trained men to care for the machinery, is, it seems to me, absolutely untenable. If it is demonstrated that an electric motor is better adapted to drive a deck winch, for example, than a steam or hydraulic or compressed-air motor,—then it should be installed, and the necessary men to operate it can, and should be obtained. If the course suggested by the naval officer referred to, had been followed in our navy for the past fifty years, we would still have sailing vessels, (the frigates and line-of-battle ships of Nelson's day,) and our recent unpleasantness with Spain would have terminated with very different results.

Assuming then as every reasonable man both in and out of the navy does assume, that electrical apparatus *can* be made to work on shipboard, let us examine the conditions of the modern war vessel as we find them, and see where electricity can be ad-

vantageously introduced, having in mind always the necessary requisites; safety, simplicity, efficiency and reliability.

The modern first-class battleship requires about 2000 I. H. P. to drive all the auxiliaries at full load, and the first-class cruiser, about 1200 I. H. P. These auxiliaries, however, are never all in use at the same time using maximum power, and it can be assumed that only about half of these amounts (*i. e.*, 1000 I.H.P. and 600 I. H. P.) will be required at any one time. They are scattered all over the ship, from the anchor hoist forward to the steering engine aft, and from the deck winches and boat cranes on the spar deck to the bilge and fire pumps in the engine and fire rooms, 30 or 40 feet below. Some of them, such as condensers, air, circulating, feed bilge and fire pumps, and fire-room blowers are necessarily located within the engine and boiler room compartments, where the temperatures are always high, and where steam, oil, water and coal-dust are always present in greater or less quantities. Others, located on the spar deck, are exposed to salt water and air and to the varying conditions of sea and weather.

With these scattered locations it is obvious that power, generated at a central point, must be distributed throughout the ship. For this purpose there can be used either steam, hydraulics, compressed air or electricity.. Hydraulics and compressed air not only have a low efficiency of conversion (from steam) but it is difficult to prevent leaks, freezing, bursting of pipes, etc. They have both been tried to a limited extent and both found wanting in service.[1] This leaves steam and electricity as the two remaining systems of distribution from which to choose. As between the two, steam has the following disadvantages:

First: Danger to life. The bursting of a steam pipe, whether in or out of a fight is a serious matter, and likely to disable any of the crew who are in the compartments where the accident occurs. It has been abundantly proven in our civil war, that men will not stand up against steam or hot water, when they will face shot and shell without flinching. Many of our vessels operating in inland waters during that war had several lines of hose coupled to a hot water tank and led out every night to guard against boat attacks. These hose were successful on more than one occasion in repelling boarding parties. While the steam main which leads fore and aft can be run below the protective deck or

1 Benborn's experience with hydraulic turret machinery.

behind the armor belt, vertical branches must run to all auxiliaries on the upper decks and many of these must be used in action. The effect of a steam pipe carrying 100 pounds pressure bursting or being shot away in a compartment where there may be 30 or 40 men, at the guns or passing ammunition, would undoubtedly be to kill or disable every man in the neighborhood and demoralize thoroughly that part of the ship. On the other hand, if a wire is shot away one or more auxiliaries may be disabled but no one is injured; furthermore, the wire presents a much smaller target than a steam pipe and is therefore less liable to injury from shot. It is always a difficult matter, too, to keep steam and exhaust pipes tight and to prevent leaks at the joints and at water-tight bulkheads.

Second: Injurious heating of living quarters. Steam and exhaust pipes must necessarily run to every auxiliary, and some of the latter, such as the ice machine, anchor hoist, steering engine, ventilators, etc., are in the officers' and men's quarters, or the pipes leading to them must pass through these quarters. The heat of the pipes and engines not only makes the quarters uncomfortable but it is impossible to prevent more or less oil and dirt around the auxiliaries. In the tropics the heat is often so great that the officers and men cannot sleep below at all. This was the case on a number of our vessels operating in Cuban waters last summer.

Third: Efficiency. Here the contrast is very striking in favor of electricity, surprisingly so to one who has not seen the actual economy figures of steam auxiliaries. Some data will be presented on this subject later on.

There remain the two important factors of simplicity and reliability to be considered. No one who has had experience with the modern well-designed and well-insulated carbon brush generator or motor, can have any doubt as to its greater simplicity as compared with the steam engine. There are no joints to be kept tight, no nuts or bolts to set up, no packing to renew, no cylinders to cut, and only two self-oiling bearings as compared with a dozen or more oilcups on an engine. In fact it is difficult to imagine a simpler piece of machinery than the modern dynamo. It seems like a return to elementary principles to discuss such a point; and yet many men aboard ship imagine the dynamo a most complicated affair, simply because they know nothing about electricity, and think everything connected with it

is mysterious and complex. This feeling is not confined to seafaring men, as we all know.

The question of reliability is a vital one, for no matter what the advantages with respect to safety, economy and simplicity may be, if the electric auxiliary cannot be relied upon at any and all times to do its work, it is a failure and must be discarded. It must not only be able to work well under normal and favorable conditions, but it must also be able to stand a certain amount of abuse and neglect. Stress of weather and other conditions, particularly during a war, sometimes play havoc with the established routine of a ship, and a sailor's tools must not only be sound; they must be hardy. The normal conditions aboard ship are not favorable to ordinary electrical apparatus, as has been explained, but this simply means that apparatus for such work must be specially designed and built to meet these conditions. The ordinary motor on shore would not last long under a street car; nevertheless thousands of car motors are built and sold every year which run day in and day out with a remarkably low maintenance account. Similarly, apparatus for ship work must be specially insulated, a larger margin of capacity must be allowed, and in exposed places it must be thoroughly enclosed. Several years ago an English manufacturer asked permission to install an electric deck winch on the spar deck of a new cruiser, fitting out at Portsmouth. When the captain who was superintending the fitting out of the ship saw it, he gave orders to have the deck hose turned on the motor for ten minutes, and then to operate the winch. The manufacturer protested and said that the motor was not intended to be abused in this way. "Then take it off the ship," said the captain, "for I cannot guarantee that we will ship no seas during our cruise, and I want that winch ready for service whether we ship seas or not." The captain was quite right, the motor was taken off and a "rough and ready" steam motor substituted.

Experience alone is the final test of reliability and fortunately we have some experience in our own navy on which to rely. During the late war, all of our regular war vessels were fitted with electric lighting plants, and many of the larger ships were supplied as well with certain electric auxiliaries; such as ventilating fans and ammunition hoists. Two of the *Brooklyn's* turrets were controlled by steam motors and two by electric motors. So far as I have been able to learn, from both official and unofficial

sources, all the electrical apparatus on these ships stood the supreme test of battle admirably, and the officers of the *Brooklyn* are enthusiastic over the performance of the electrically controlled turrets. They report that with respect to ease of manipulation and fineness of control, there is no comparison, but rather a contrast. This is high praise from competent authority, for the officers referred to had actual command of the turrets in battle, and their judgment is not only unprejudiced and impartial—it is final and conclusive.

It is hardly necessary to say that electric machinery to be reliable must have reasonable care and attention from men who know something about it. The same is true of *any* machinery and it is bad policy, as well as untrue, to say, as is sometimes said by those who should know better, that an electric motor requires no attention. Cleanliness is very necessary, and may be considered as a first essential to successful operation. It is astonishing to see how little has to be done to an electric motor if it is kept scrupulously clean; but this cleaning must be regular and intelligent. From what has been said, it may safely be affirmed that electric machinery can be made as reliable on shipboard as any other machinery, and with this in mind we can turn to the question of efficiency, including weight of plant and first cost.

There has been very little data published on the performance of ship auxiliaries, but a valuable contribution to the subject appeared in the February (1898) number of the *Journal of the American Society of Naval Engineers*, by P. A. Engineer, W. W. White, U. S. Navy, entitled, "Steam Consumption of the Main and Auxiliary Machinery of the U. S. S. *Minneapolis*." This vessel, as is generally known, is a first-class protected cruiser of about 7500 tons displacement, with three screws (each operated by its own engine) and a trial speed of over 22 knots per hour. She represents the highest type of her class, and is in every way a credit to her designers and builders. She has between thirty and forty steam auxiliaries, and more than 150 separate steam cylinders. Her only electric auxiliaries are the lighting generators and a few small ventilating sets and ammunition hoists. In order to ascertain the steam consumption of her main engines and auxiliaries, Mr. White, who was serving on board the *Minneapolis* at the time, as one of her engineers, made a series of careful observations during a run of the vessel of seven days from Gibraltar to League Island, Philadelphia. Indicator

cards were taken on all auxiliaries fitted for the purpose (31 in number), and the losses from leakage, condensation and radiation were carefully estimated and the water evaporated accurately measured. The results obtained are given in the following tables (marked I. and II.), and they are certainly startling.

An estimate of the average weight of steam used per hour by the machinery in operation is as follows.

TABLE I.

	Total pounds of steam per hour.
Main engines, port and starboard	31,939.8
Condensation from main engine jackets, estimated	750
Condensation in main steam line, estimated	450
[1] Loss of steam from unavoidable leaks, estimated	480.8
Total	33,620.6

AUXILIARIES.

Main air and circulating pumps	2,641.9
Bilge pumps, (three)	1,291.2
Steering engine, estimated	450
Main feed pump	951.1
Pump for washing decks, ash hoists, galley coppers, shop engine, etc.	240
Dynamo	2,023.3
Flushing pump	275.7
Blower in evaporator room, and combined salt and fresh water pump for distilling plant	46
Steam to evaporators for distilling (average of 1,500 gallons per day)	651
Ship's ventilating blowers, (two after)	549.4
Ship's ventilating blowers, (two forward, 12 hours per day)	274.7
Ice machine	412.4
Miscellaneous (shifting of dynamos, etc.)	30
Condensation in auxiliary steam line, estimated	300
Total, auxiliaries	10,136.7

Hood's Merthyr coal was burned, there being three main double-ended boilers in use.

DIMENSIONS OF EACH BOILER.

Length, feet	20
Diameter, feet and inches	15–9
Furnaces, number (corrugated)	8
Furnaces, diameter (least), inches	40
Furnaces, diameter (greatest), inches	$42\frac{7}{8}$
Length of grates, inches	84

1. Assumed as one-half the total loss of feed water per hour.

Tubes, number	1,268
Tubes, diameter, inches	$2\frac{1}{4}$
Tubes, length between tube sheets, inches	$87\frac{3}{4}$
Tube heating surface, square feet	5,540
Plate heating surface, square feet	861
Total, heating surface, square feet	6,401
Grate surface, square feet	186.7
Ratio G. S. to H. S	1 to 34.29

RESULTS.

Average boiler pressure, by gauge	142
Coal consumed per hour, pounds	5,215
Coal consumed per hour, per square foot of grate, pounds	9.31
Refuse per hour, pounds	637.5
Percentage of refuse in coal	12.22
Total steam used per hour, all machinery, pounds	43,767.3
Pounds of water vaporized per pound of coal (average temperature of feed 85°)	8.39
Equivalent evaporation per pound of coal from and at 212°	9.89
Percentage of daily coal consumption to run main engines only	76.82
Percentage of daily coal consumption to run auxiliary machinery	23.18

It will be seen that the average weight of steam used by the main engines per hour was 33,620.6 lbs., and by the auxiliaries, 10,146.7 lbs. That is, the auxiliaries consumed nearly 25 per cent. of the total coal used. The main engines consumed an average of 20.83 lbs. of steam per I. H. P. per hour, and the auxil-aries an average of 119 lbs. per I. H. P. per hour (the lowest being 55.06 lbs. and the highest 318.68 lbs. per I. H. P. per hour). An examination of Table II. shows that the steam consumption of the same or similar auxiliaries varied greatly, due doubtless to the varying conditions of packing rings, bearings and valves, and of the load. These results are not exceptional; in fact, they are probably better than the average obtained on most war ships or merchant vessels. The new British cruiser *Powerful* (14,000 tons displacement) is reported to have used 8,300 tons of coal, from England to Hong Kong, of which 3,400 tons (or over 40 per cent.) were required for the auxiliaries.

Under the most favorable conditions the auxiliaries of a large ship probably consume at least 20 per cent. of the total coal and water used. This is more than twice as great as the consumption of a modern central station, and there is no good reason why as good results should not be obtained afloat as ashore.

Let us assume a required central station capacity for a first-class battleship of 1,000 H. P. effective at the motors. The present

TABLE II.

SUMMARY OF TESTS TO DETERMINE STEAM CONSUMPTION OF THE MAIN AND AUXILIARY MACHINERY OF THE U.S.S. *MINNEAPOLIS*

Engine Tested.	Number of test.	Dimen. of engine: No. steam cyls	Dimen. of engine: Cyl diam: Steam.	Dimen. of engine: Cyl diam: Water.	Dimen. of engine: Stroke (full.)	Double strokes or revolutions per minute.	Duration of test.	I. H. P. of engine from cards.	Condensed exhaust steam: Per hour.	Condensed exhaust steam: Per I. H. P. per hour.	Remarks.
			ins.	*ins.*	*ins.*		*h. m. s.*		*pounds.*	*pounds.*	
Main starboard engine	1	3	42 59 92	..	42	53	....	610.85	12,973.	21.237	Average of 7 tests.
Main starboard engine	2	3	42 59 92	..	42	60	.....	781.39	15,959.	20.431	Average of 8 tests.
Steam cylinder, S. auxiliary condenser	3	1	8	..	12	33.20	5.21.00	1.232	328.07	266.30	Combined air and circ pump
Center circulating pump	4	2	10	*36	6	171.6	3.07.05	18 873	1,039.14	55.06	Approximate power developed on official trial.
Center circulating pump	5	2	10	*36	6	90.0	2 49.30	4.104	310.86	75.74	Slide valve altered Forward cylinder only taking steam.
Center circulating pump	6	2	10	*36	6	89.5	2.11.00	4.039	402.33	99 61	After cylinder only taking steam.
Starboard circulating pump	7	2	10	*36	6	82.0	3.28.20	2.017	252 63	125.28	I.H.P., main engine, 604.
Starboard air pump	8	2	16	31½	21	16.6	2.58.10	6.543	1,195.70	182.74	I.H.P., main engine, 604.
Center air pump	9	2	16	31½	21	15.2	3.02.42	25.181	1,969.90	78.23	Pump loaded by opening salt feed valve.
Starboard water-service pump	10	2	7½	4½	10	40.9	2.59.00	1.039	212.92	204.05	Pump used for flushing purposes
Center fire and feed pump	11	2	12	8½	12	12.7	3.30.45	.7851	250.19	318.68	Pump used for flushing purposes.
Center fire and feed pump	12	2	12	8½	12	37.3	1.45.30	6.412	999 23	155.84	Pump used for washing decks.
Center fire and bilge pump	13	2	14	9	12	27.7	2.02.30	2.519	430.43	170.87	Pump used on bilges.
Main fire room feed pump	14	2	12	7½	12	11.02	2.23.20	8.828	806.94	91.41	Pump used for feeding steaming boilers.
Main fire room feed pump	15	2	12	7½	12	2.61	3.27.00	1.573	382.00	242.85	Pump used for feeding auxiliary boiler.
Forced draft blower engine	16	2	5	..	4	595.3	1.23.35	16.300	1,262.30	77.44	Fire room closed in air-tight.
Ash-hoist engine	17	2	4½	..	4½	....	50.00 24.00	.....	.. .	......	
Dynamo engine, No. 1	18	2	10½	..	5	408.7	24.00.00	21.873	2,695.60	123.27	Steam pistons water-packed, and bad fit to cylinders; cylinder bores rough and pitted.
Dynamo engine, No. 1	19	2	10½	..	5	424.3 417.0	1.15 40 1.20.10	19.598 33.601	1,737.1 2,293.2	88.64 68.25	New pistons with two cast-iron packing rings in each; in use about 10 days.
Dynamo engine, No. 1	20	2	10½	..	5	415.1	24.00.00	29.184	2,023.3	69.33	New pistons with packing rings in cylinders.
Dynamo engine, No. 2	21	2	10½	..	5	391.1 388.7	2.48 00 1.29.06	19.012 30.354	2,066.8 2,550.7	108.71 84.03	Water-packed pistons; cylinder bores rough.
Dynamo engine, No. 2	22	2	10½	..	5	392.0 390.7	2.02 00 1.33.25	16.791 26.553	1,725.0 2,250.0	102.73 84.74	Water packed pistons; cylinder bores rough.
Dynamo engine, No. 2	23	2	10½	..	5	425.0 425.0	1.10.25 26 25	22.923 35.237	1,492.7 1,989.2	65.12 56.45	New pistons with packing rings; in use about 9 days.
Dynamo engine, No. 3	24	2	10½	..	5	404.3 388.3	2.00.00 1.35.26	17 324 26.234	1,693.4 2,085.1	97.75 79.48	Water-packed pistons; fit cylinders closely. Cylinders in good condition.
Dynamo engine, No. 3	25	2	10½	..	5	398.0 382.5	2.03.45 1.44.50	18.241 27.815	1,488.8 2,006.5	81.62 72.14	New pistons with packing rings; in use about 4 days.
Dynamo engine, No. 3	26	2	10½	..	5	390.0	12.00.00	20.40	1,962 5	97 92	Water-packed pistons.
Flushing pump	27	1	8	9	12	31.7	3.11.15	1.421	275.7	194.02	
Ventilating blower engine	28	2	4	..	3	277.5 404.3	1.59.50 52.30	....	274.65 501.23	....	No indicator motion fitted.
Ice machine engine	29	1	7	.	10	73.1	5.12.05	6.024	422.38	70.12	
Workshop engine	30	1	6	..	6	175.1	2.58.00	.....	148.05	......	No indicator motion fitted.

*Two fans.

Tests Nos. 1, 2, 7, 8 and 14 were made at sea, the others while at anchor,

standard E. M. F. for naval installation is 80 volts, and for the merchant marine about 100 volts. This low voltage was originally adopted on war ships on account of the searchlights, which require 50 volts only, and it was desired to introduce as little dead resistance as possible. At this time no motors were of course in use, and the electric plant was used for lighting exclusively. Such a voltage is, however, entirely unsuited for a 1000 H. P. plant. The weight of the distribution system would not only be excessive, but the size and weight of the generators would be prohibitive. The three-wire system, or a standard of 220 to 250 volts two-wire system should be adopted, using the necessary resistance in the searchlight circuits when they are in service; since they require a relatively small percentage of the total plant capacity, and are not regularly in use, this can be done without undue sacrifice.

The generating plant should consist of several units of the same size, so that parts are interchangeable, each unit consisting of a compound vertical engine driving a pair of generators or a single generator, depending upon whether a three-wire or two-wire system is used. Assuming an efficiency of 82 per cent. for engine and generator, and an average line and motor efficiency of 80 per cent., the total efficiency of the system (between I. H. P. of the generating engines and the effective H. P. of motors) is 65.6 per cent. In other words, to develop 1000 H. P. at the motors will require 1500 I. H. P. at the engines, or about 900 K.W. generator capacity. Six sets of 150 K.W. each, with one in reserve, would be required. A good compound engine working at approximately full load (and with six units, those in active service can always be operated at or near full load), will require 20 lbs. of steam per I. H. P. per hour. Assuming a total efficiency of the system of 65.6 per cent., as above, it will require about 30 lbs. of steam per effective H. P. per hour *at the motors*. If we allow 25 per cent. margin for losses due to steam leakage, condensation, mechanical friction of gears, etc., we still have an economy of *37.5 lbs.* per H. P. per hour as against 119 lbs. as shown by the *Minneapolis* test. In this case the auxiliaries tested aggregated 471 H.P. developed, using 56,049 lbs. of water per hour. At 8 lbs. of water evaporated per pound of coal, the coal consumption was 7000 lbs. per hour, or 84 tons per day, assuming that this power was required for 24 hours. If the water consumption had been at the rate of 37.5 lbs. per I. H. P. per hour instead of 119 lbs.,

the coal used per day for these auxiliaries would have been 26.5 tons, a saving of 57.5 tons, or nearly 70 per cent.

It is fair to assume that by the introduction of compound engines and approved mechanical appliances on some of the auxiliaries, the average steam consumption can perhaps be reduced to 75 lbs. per H.P. per hour, but this is still 100 per cent. in excess of that required for the electric drive. Assuming a average daily use of 800 H.P. effective at the auxiliaries on a first-class battleship at sea, this difference in efficiency means a saving in water used of 360 tons per day, and in coal a saving of 45 tons per day. All steam cylinders connect with the condensers, so that the water used by the auxiliaries is not lost but is used over and over again, it being necessary to supply only that lost by leakage in the pipes and condensers. The extra pumping duty is large, however. The coal saved, on the other hand, means that with a given coal endurance (or "steaming radius") a vessel can carry from 10 to 20 per cent. less coal, or expressed in another way, with the same coal capacity, she will have from 10 to 20 per cent. greater steaming radius. The average price paid in the navy for coal (including stations in all parts of the world) is probably at least $7.00 per ton. There is therefore in the case assumed, a direct saving in running expense of $315.00 per day for coal alone. It may be argued that a vessel in port does not use her auxiliaries to the same extent that she does at sea, and that, therefore, the comparisons made are misleading. This may be true as to actual savings in pounds of coal and water, or in dollars and cents, but the percentage differences hold true in any case. Furthermore, a ship is built to keep the sea, and her efficiency and usefulness are measured by her performance at sea, and not when incidentally or accidentally in port. Her weights are distributed or apportioned, and her power, speed and "steaming radius" are designed for *sea conditions*, and these conditions alone should be considered.

The weight and space required for plant are important matters; for a modern steamship, and particularly a war vessel, has every available inch of space and pound of weight carefully allotted; and it is sometimes difficult for the designers to adjust the conflicting elements (which may be equally important) so as to provide for all, and still keep within the prescribed limits. The present weight of steam auxiliaries of a first class battleship, assuming a total capacity at full load of 2000 H. P. as before, is

about 200,000 lbs. or 100 tons. If the electric drive is used, we must add the weight of the generating plant. The navy specifications limit this weight at present to one third of a pound per watt of rated capacity. With 1050 K. W. capacity (six units of 150 K. W. for service and one for spare) the weight would be 350,000 lbs. or 175 tons. The electric auxiliaries would weigh about the same as steam, or 100 tons, a total of 275 tons as against 100 tons for steam drive. There would be some saving in the wiring, as against steam and exhaust pipes, so that it may be assumed that the electric plant, with the generating sets described, will weigh between two and one half and three times the steam drive. As an offset, however, we have the saving of 10 to 20% in coal required for a given steaming radius, which in a ship of this class would amount to between 200 and 400 tons. Furthermore, if in the future a satisfactory steam turbine, comparable in economy with the compound engine, is developed for marine work, as now seems probable, the weight of the generating plant will be reduced 40 or 50%, and then the electric drive will compare favorably in this respect with steam, and there will still be the saving in weight of coal required for a given endurance.

The space necessary for plant must be considered as one of the vital parts of the ship, and as such it must be located below the protective deck. At first thought it may be said that it will be difficult to find the necessary space, but it must be remembered that the space required for 200 to 400 tons of coal. is available, in addition to the space at present allotted for dynamo room, and these combined will certainly be more than sufficient.

The application of the electric drive to the various ship auxiliaries must be carefully studied in each case.. The problems involved, however, are not more difficult than many special applications on shore, nor is there anything about them which a competent electrical engineer, with a proper knowledge of *sea conditions*, is unable to solve. The first cost will undoubtedly be greater than with the steam drive, but the saving in "operating expense," if capitalized, will much more than offset this difference in first cost.

The problem is purely an engineering one, and should be approached in a business-like way. Will the electric drive be equally safe, simple and reliable, and will it be more efficient than the present system of steam drive? This is the question in

a nutshell, and I believe that the figures and data which I have presented enable us to answer it most emphatically in the affirmative. Other nations, particularly England, Germany and France, have already introduced the electric drive extensively on their ships, both in the navy and in the merchant marine; and it is earnestly to be hoped that our own navy, with its magnificent ships, officers and men, of whose record we are so justly proud, will not lag behind in this important respect. Once provide the proper tools, and there need be no fear in this country that the necessary men to handle them properly will not be found.

I have not touched upon some of the minor electrical applications which have been made aboard ship, such as searchlights, range finders, engine room telegraphs, speed and helm indicators, signal sets, telephone, etc. Some of them, such as the signal sets and searchlights, are of considerable importance both from the military standpoint and for navigation purposes, and have stood the test of service admirably. Others, like the range finder and telephone, while of great utility, have not yet demonstrated that they can be relied upon at all times; while others still, may be considered as luxuries (sometimes of doubtful utility) rather than necessities. All of them come within the province of the electrical specialist, rather than the electrical engineer, and have no direct bearing on the main problem discussed in this paper.

APPENDIX.

Since the reading of the above paper, an article has appeared in the March 1899 issue of *Cassier's Magazine*, entitled "The Outlook in Marine Engineering," by Engineer-in-Chief George W. Melville U. S. N., from which the following extract is given. It will be seen that his statements confirm those given in the paper with reference to the uneconomical performance of steam auxiliaries aboard ship.

S. D. G.

Schenectady, N. Y.
March 6th, 1899.

Auxiliaries.

As was stated previously, the problem of the economy of auxiliaries has become a very important one, as the aggregate horsepower of the auxiliaries on a large ship is now considerably more

than the horse-power of the main engines of good-sized vessels of twenty years ago. A paper by P. A. Engr. W. W. White, U. S. N., published last year, set forth the facts in regard to the steam consumption of all the auxiliaries of one of the finest war vessels in the world,—the U. S. triple-screw cruiser *Minneapolis*, —and this is, undoubtedly, a typical case. As shown by that paper, the steam consumption of almost every auxiliary engine on the ship was high, while of some it was enormous.

Various solutions of the problem have been proposed. One is to have a sort of central pump station where a very economical triple-expansion engine would furnish the power and all the pumps would be driven by it.

Another is to make the cylinders of the auxiliary engines, in effect, a part of the intermediate cylinder by having them take their steam from the first receiver, and exhaust into the low-pressure receiver. For merchant steamers which make long runs under absolutely uniform conditions, this would seem to be a very satisfactory solution ; but for naval vessels, in which facility for manœuvring is so important, even if this were adopted, it would be necessary to have an arrangement of valves, readily changeable, to throw the pump cylinders out of the circuit and have them take steam from the auxiliary steam pipe and discharge to the condenser.

Another plan is to compound all the engines which have hitherto used steam with only one stage, and that really without expansion at all. This would, undoubtedly, materially increase the economy, but in some cases it would, undoubtedly increase the weight.

Still another solution is the use of electric motors for driving nearly all the auxiliaries. The advantage claimed is that the efficiency of both motors and generators is so high that their combined losses will reduce only slightly the benefit to be derived from supplying the power for the generator from a very economical engine rather than having a small steam-engine to drive each auxiliary.

This last solution is one which has been applied to some extent for such auxiliaries as hoists, winches, and turret-turning gear, and, as far as the working of the auxiliaries is concerned, the result is entirely satisfactory. There are also certain facilities for installation and handling which commend this system above that of small steam-engines located at a considerable distance from the boilers. The problem, however, is a difficult one, and, for its thorough solution, requires more investigation and analysis than many writers have given it.

Even more important than the economical development of power, are the items of reliability and adaptation ; and the questions of weight, space occupied, and first cost must also be considered. For instance, from many points of view it would seem that the capstan and steering engines afforded examples

where the electric power would have great advantages on the score of facility of installation; yet many strong advocates of motors for other purposes oppose them here on the ground that electric apparatus is not sufficiently reliable for these important places.

Again, from some considerations, motors would seem specially adapted to the forced-draught blowers, but when we reflect how rarely these are used on naval vessels, and that the electric plant to run them (including engines and dynamos) will weigh more than three times as much as steam engines, and probably exceed the cost in a still higher ratio, it becomes nearly certain that it would be far from economical to install motors for this purpose. These illustrations are given to show that it would be unwise to be stampeded into using electric appliances everywhere because they are the best for certain situations.

Mr. George W. Dickie, the talented manager of the Union Iron Works, of San Francisco, has suggested that the solution of the problem could best be determined by taking several ships of absolutely identical design otherwise, and fitting them with different systems of driving the auxiliaries, but having all the auxiliaries of any one driven by one system. The trouble, at present, is that the different methods of driving the auxiliaries are mixed on each ship, so that it is impossible to make an accurate comparison from the results obtained in daily working, on account of the great difficulty of determining the economic performance of each auxiliary separately.

Meanwhile, it should be noted that in all the latest United States naval designs, feed heaters are fitted, through which the auxiliaries can exhaust, thus causing a decided increase of economy; and provision is also made for exhausting (while the main engines are in operation) into one of the receivers. This last practice has prevailed for some time in American ships, and is attended by a considerable saving of coal.

Discussion.

The President:—I feel sure we have all listened with pleasure to Mr. Greene's paper and it is gratifying to learn that electrical appliances have behaved so well on board naval vessels in practical work. I know that you must have a number of questions to ask, and I am sure that Mr. Greene will be glad to answer them.

Mr. John W. Lieb, Jr.:—In the comparison of weights I did not understand if the weight of the electric drive included the motors at various points on a ship together with the generating side.

Mr. Greene:—Yes.

Mr. T. Commerford Martin:—Reference was made to the work that was done by means of the motors driving turrets. I think that is one of the most important steps taken in the application of miscellaneous electrical apparatus to our men-of-war. I notice that we have with us this evening Mr. H. Ward Leonard to whom I believe belongs the credit of that advance, and I think we should all appreciate it very much if he could give us a few details with regard to that very important application.

Mr. H. Ward Leonard:—I think that a good many of those present are probably quite familiar with the essential features of the method of control that is used on the turrets, as it is the simplest form of the various modifications of the methods of control that I have described before the Institute. It is, practically speaking, merely this—a motor and a generator, practically identical, (although the speed of them need not be the same, but identical as regards voltage and output) have their armatures connected metallically together, so that, speaking popularly, the armatures are short-circuited upon each other. The field of the motor is fully excited at all times, and the generator has in its field the winding which is similar to the shunt winding of an ordinary generator, a field rheostat, which not only enables you to vary the current over a very wide range that passes around the field of the generator, but permits you to reverse that current. The generator armature being driven at all times at full speed, and in this field which can be varied from zero intensity to full intensity in either direction, the field current supplied being from a separate course of constant electromotive force such as the lighting circuit, you will see that a very ready method is offered of obtaining at the brushes of the generator any voltage, from zero to the maximum voltage, and this voltage in either direction. Since the field of the motor is constant, any reversal of the voltage of the generator will cause the current to flow in the reverse direction in the armature circuit, and consequently cause a reversal of the motor armature. The point which is perhaps of the greatest importance to make clear, is the very perfect control which you obtain under such conditions due to the fact

that the two armatures are, as far as voltage is concerned, electrically locked together. It is impossible that the voltage upon the terminals of the motor armature and the voltage upon the terminals of the generator armature should differ, except by the drop in the very low resistance metallic circuit formed by the two armatures short-circuited together. Consequently, it is quite different in this regard from any case in which a large percentage of drop is occasioned by the passage of the current through some rheostatic resistance. We can with this arrangement say with positiveness that if we produce a certain definite field in the generator, which means if we place our rheostat at a certain definite contact, the voltage of that generator will be fixed, and hence the voltage supplied to the motor armature in a constant field will be fixed, since the speed of the motor will be in proportion to its counter-electromotive force, and therefore practically in proportion to the voltage of the generator in the system. The speed of the motor becomes definitely fixed, and there will be a definite speed for each position of the generator field rheostat, and this speed will not be dependent, as would be the case with the rheostat controlled motor, upon the torque of the motor, but on the contrary will be practically independent of the torque. Since the motor field is entirely independent of the armature current it is possible to obtain a speed which under all conditions of load will be exact and precise, and hence any desired speed over the entire range from the slowest motion to the full speed, can be readily maintained. Another point which is of great importance and is peculiar to this arrangement is, that it is quite easy to control the speed not only in accelerating the speed, or maintaining the speed, but also in retarding the speed or stopping the motor, as the motor will instantly become a generator in case we lower the field of the generator so that the voltage of the generator would tend to fall below that of the motor. In the case of the application in question, where there is a very large weight, if it is in motion at a certain speed and it is desired to reduce that speed or bring the motor to rest, a very rapid but extremely gradual retardation of the load is effected by the insertion of resistance in the generator field which drops the voltage of the generator below that of the motor. The motor consequently becomes a generator and sends a large current around the armature circuit in the reverse direction, thus tending to increase the speed of the prime machine, formerly the generator, now acting as a motor, which in turn delivers that energy to the original source as useful energy. One point that I think perhaps may not be evident, but is of importance, is that in the acceleration or retardation of a large mass, the very best results can be obtained when the force which is going to cause the acceleration or the retardation, is produced in such a manner that the energy is in proportion to the square of the velocity. The action of a ship coming to rest in the water, as we all know,

is extremely smooth, and when the ship does come to rest in such a way we do not feel any such effect as tending to fall forward or backward; our motion is retarded in such a manner as to be entirely natural, and the action of the water opposing the motion of the ship and comparable to the torque, is such as to be proportional to the square of the velocity. In the electric circuit as it exists in the armatures, joining the generator and motor in question, the speed is proportional to the volts, and the relation thus obtained enables one to get an acceleration and a retardation which is comparable to that which is met with in the case I have described, and it is impossible to secure by the ordinary methods any such smoothness of stop. As I think has been very clearly brought out in a great many papers in connection with the braking of trains, the torque of a mechanical brake is greatest at the time when the speed is lowest; whereas for proper retardation the braking effect should be very much greater at the time when the speed, and consequently the momentum of the load, is highest, and the braking effect should taper off rapidly as we come towards rest, which is exactly the reverse of the conditions which are met in a mechanical brake of the ordinary kind. This is familiarly known to us from the fact that a man on the old form of street car could, when he was bringing the car to rest, jam his brake strongly while the car was going pretty fast; but in order so make a smooth stop must necessarily greatly relieve the brake as he came toward rest, or else the stop would be very disagreeable.

I am not familiar with the exact details of the arrangement for the *Brooklyn*. The installation was made by the General Electric Company, who are licensees under my patents, and I never have myself seen the installation on the ship, but it is practically as I have described as regards the electrical conditions. Of course, it is a great source of pleasure to me to find that the system is working so successfully, and while it of course does not surprise me, I think the perfect operation of the system will probably surprise a good many of the people who have thought in the past that the system could not possibly have the features of simplicity and perfection of control, both in acceleration, retardation and reversal, that I had claimed for it. As perhaps a good many may remember, it was thought by those who criticized the system that necessarily difficulties and insuperable difficulties would be met, as regards the sparking of the generator; but in a well designed generator of modern type no difficulty of this character is met with. Quite a number of members who have discussed this system before the INSTITUTE in the past have thought that while it might have some points of advantage, that it practically was equivalent in its effects to a rheostat control, except that the power that was wasted in a rheostat was saved, and also that a good many, and perhaps all of the effects of the system could be accomplished

by means of a series-motor, or perhaps some form of compound motor, but this is not correct, as there are peculiar effects in this system which are not met with where anything equivalent to resistance is introduced in the armature circuit, or where any material disturbance occurs in the field of the motor that is being controlled.

I am sorry to note from the most recent reports that the decision of the parties in control of naval affairs seems to be unfavorable, as regards the use of electric motors except for the turrets; but it seems to me that with such evidence as is being forced upon their attention by papers such as this, that in a very short time the electric motor, with its advantages manifest to all of us, will take the place of the steam motors for the auxiliaries.

One point that has been touched upon by Mr. Greene but perhaps not emphasized as much as it might be, is the fact that there is a very wide diversity of efficiencies in engines of the same duty and the same size, and this is a difficulty which it seems to me is always inherent in steam engines; there is not the same possibility of ready measurement of the power that they are consuming, and there is always the probability that some portion of the engine may be packed too tight, or that there may be some cutting, and we all know that it is reasonable to expect, if we have two 5-horse power motors, for example, of the same make operating under the same kind of duty, that their performance would be uniform and their efficiency would be practically identical, and that if there were by any chance, conditions that made the efficiency of one poor compared with the other, that it would be a matter of the simplest kind to make a measurement in a few moments that would show conclusively by the ampere-meter the difficulty that existed and immediately locate it, and thus save a waste of power which would be likely on the other hand, to go on indefinitely in steam engines. I thank you very much for your attention.

Prof. Elihu Thomson:—I happened to make a trip about two or three months ago to Washington for the express purpose of convincing the department, as far as I was able to, that electricity was the only thing to use on shipboard, in place of these numerous steam plants. As I thoroughly believed that to be the case, I made the best plea I could of course. I found, however, that in one of the departments especially, there seemed to be an idea that we should move slowly; do one thing at a time and test what we had done before leaping in the dark. That might be a rational estimate of the situation coming from one who probably had not looked into the comparison between these various sources of power and electrical power. However, I am perfectly satisfied that the time is short when it must come about that an electric equipment, on account of its numerous advantages, will be adopted for practically all of this distribution of power around

a ship, just as it is being adopted for the distribution about a large city. The reasons are even more cogent in the case of a ship where the coal consumption is a vital factor. One cannot look at the tables presented by Mr. Greene, without seeing the enormous coal consumption of some of those small powers, and yet I know it also as an experimental fact, that engines as small as four horse power can be made to develop a brake horse power, not indicated—on about 20 pounds of water per horse power hour; that engines probably of larger capacity can be made to go very much below this, and those engines will be simple, non-condensing engines, uncompounded. Now I make that statement advisedly because I have been experimenting for a year in that direction. Engines of this kind can be turned out in any machine shop without any particular difficulty, being as easy to make as any simple engine. I find curiously enough that after doing a considerable amount of work in this direction, M. Serpollet of Paris has recently published a statement concerning a steam engine as applied to horseless vehicle work, and I find further that his engine is about the same as mine. This goes to show that we have been thinking pretty much in the same groove. I need make no secret as to what the engine is, because M. Serpollet has published it, although of course our patents are pending. But it is so simple that it is astonishing that something of the kind has not been used or at least experimented with before. If it takes over twenty pounds per horse power—and *indicated* horse power as noted in that table—(referring to one of Mr. Greene's tables) in the main starboard engine, and we can do as well with a non-condensing simple engine of four horse power, we have certainly done something worth while. My reasoning was this: that the gas engine is an efficient engine and that I must run my steam engine on the same principle of the gas-engine. In other words, I must imitate the cycle of the gas engine in steam, and then I would get high efficiency, with other advantages. If I represent an ordinary steam cylinder as an open-ended cylinder in Fig. 1, and put a piston P in that cylinder, well packed by rings, and either use a straight piston rod and guides in the ordinary way, or the connecting rod R jointed to the piston, we have the type of engine as it stands. Now instead of reversing the motion of our steam as it enters back of the piston and throwing it back to the heated surfaces in exhausting, we are careful never to throw it back, but always let it go forward. We make an exhaust consisting of a number of holes uncovered by the piston at the extreme outward portion of its stroke as at E. The piston is moving slowly when it is out here near E and there is plenty of time, if the holes are made around the piston, to discharge all the steam. In order to use the steam superheated so as not to burn the valves or injure the engine, and we use somewhat superheated steam, or quite dry steam, we simply have here a poppet valve V which is raised by

proper valve mechanism in time with the rotations of the crank. The steam supply pipe from the steam generator is at S. Now let us see what we can get in this engine. In the first place let us suppose the engine cylinder has been exhausted of steam at E to atmospheric pressure. If we construct an indicator diagram, Fig. 2, calling base line atmospheric pressure, we reach the end of our stroke at *e*. Instead of letting the piston go all the way up to the end of the cylinder we can allow a clearance space which represents the clearance space in a gas engine. We can thus allow a certain compression; and the compression can nearly equal the boiler pressure, or it may fall below it. This seems to make but a slight difference. We have, therefore, adiabatic

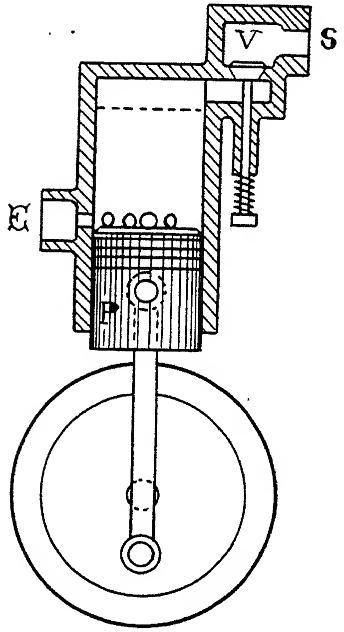


Fig. 1.

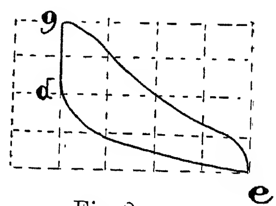


Fig. 2

compression with a slight heating during the compression line along *e d*, Fig. 2, because the steam left in the cylinder is being driven up towards hot surfaces, those that have been heated by the live steam. Then we have valve V opened suddenly, and pressure rises to boiler pressure *g*. The valve V stays open but a very short time, and expansion takes place from *g* to *e*. The diagram resembles a gas engine diagram. What is left in the cylinder is again driven up and compressed. Now what is the result? There is a temperature gradient from one end of the cylinder to the other. The steam always coming in hot, cools off by expansion; by the time it gets to E it is ready to go out. It sweeps out all water of condensation—explodes it out or blows it out,

and what steam is left in the cylinder is driven back on hot surfaces, dried, superheated; the poppet valve opens and makes as it were an explosion of steam; remains open but a small time and expansion brings the pressure down again and so on. The engine with four cylinders, $2\frac{1}{2}''$ in diameter, $3''$ stroke has given the result of $20\frac{1}{2}$ pounds water per horse power hour.

MR. GREENE:—What steam pressure?

PROF. THOMSON:—160 pounds, anywhere between 160 and 200 pounds. No doubt it can be made to run with higher pressures. There is no question about that. It could be run on 300 pounds easily enough. The result of it would be that if we needed engines to equip boats very rapidly in case of a war we could turn such engines out in a very short time. We need not wait to make elaborate compound condensing engines. This small engine does not condense at all; the escape is outwardly to the air. We made careful brake tests, driving a dynamo and loading the dynamo, and against the results of test is the transmission by a chain and the bearing on which the dynamo ran. That is, we really ought to allow about five per cent more, which would bring the steam down to about $19\frac{1}{2}$ pounds per brake horse power hour. With a large engine I see no reason why it should not go down to something like 15 or 16. Surely we ought to gain something with increase of size. But notice the conditions. The conditions are such that there is no re-traversing of passages, no re-traversing of even the cylinder portion. The steam enters, goes forward and out, and it is running steadily forward, so that we do not have any of those inter-actions that use up energy. We have a temperature gradient from one end to the other of steam cylinder. We use superheated steam, highly superheated if we please, because the engine is like the gas engine which can use flame. We have run it at all degrees from moderate superheating up to red heat. The engine has been operated with the steam pipe red hot right up to the engine, but our tests were made when it was at a moderate superheat.

MR. TOWNSEND WOLCOTT:—I would like to ask Prof. Thomson if there is anything equivalent to variable cut-off in this type of engine.

PROF. THOMSON:—Yes; we have a variable cut-off, although we usually run it at full load with a very small time for feeding steam. In starting, we of course give steam during a good portion of the stroke of each of the four cylinders. In order to get continuous torque in this case, we give it for about two-thirds of the stroke.

MR. WOLCOTT:—One of the chief drawbacks to the ordinary gas engine is that there is very little speed regulation, and then when running too fast a stroke is lost and it don't take gas on that stroke.

PROF. THOMSON:—There is no difficulty whatever in this case. We have in fact a variable cut-off arrangement whereby we can

give a little more or a little less steam or run on compression alone for a few revolutions.

LIEUT. WALLING:—I have listened with much pleasure to the instructive paper read before the INSTITUTE this evening, and being here in the capacity of a listener, without expectation of taking any part in the discussion, my remarks on the subject of the lecturer's paper, a subject with which I have been intimately associated for the past two years, must be more brief than I should desire. In all the discussions which come up regarding electrical installations on board ship there are a great many things to be considered that I do not think are understood in commercial life, for electric appliances of all kinds have their severest tests in naval installation.

In regard to the *Minneapolis* and the use of steam and coal for auxiliaries; we have made several tests on board ships on dynamo engines for water consumption. I am not aware that it is known to the INSTITUTE but we have gone through a long series of types of engines each tending toward better efficiency and are now using the tandem compound. We are now getting an efficiency of about 21 pounds per indicated horse-power and about 30 to 32 per kilowatt hour. We started out with engines that I think must have, on original tests, given about 65 pounds per indicated horse-power, and have later come down to about 48 on the improved types. The *Minneapolis* had pistons that were not packed and wore badly. They were of rather soft material. The steam short-circuited from one side of the piston to the other. In a similar type of engine, almost the same type, used on the *Marblehead*, there was 125 per cent. increase in a period of two years. You cannot get good coal economy with that kind of an engine. We repaired the *Marblehead's* engines, packed the pistons, and have never had any like trouble since. We took the matter up then with the company which made the engines. They have since packed pistons and their engines have done very well.

The case of the *Marblehead's* engines has been repeated in a number of ships and, until I heard the data given in this paper, I was not aware that the economy of other auxiliaries had ever been effectually tested.

The installation of electrical appliances for working all auxiliaries on board ship will, I think, be very general within the next two years. There are, however, two types which we will be rather slow in changing from steam drive, namely, the anchor gear-windlass or capstan—and the steering gear. It is still a question as to the availability of motors for their use. Motors will answer for most of the uses in commercial life; but for anchor use, when a ship is pitching badly in a heavy sea and her anchor must be weighed, the motor may or may not be reliable, and we cannot take the chance that it may not. It is mainly a question of application. With steering gear a similar condition obtains from the "kicking" of the helm in heavy weather.

The question of voltage has been mainly one of insulation and loss in searchlight rheostats: the commercial practice of placing two arc lights in series having some undesirable features on board ship, mechanically, and in the intended use of the searchlight itself.

Ship grounds, whether the wire be in molding or conduit, are frequent and troublesome and therefore low voltage is desirable.

We are using $\frac{1}{64}$ pure rubber and $\frac{2}{32}$ vulcanized, in addition to tape and braid, on our branch conductors of No. 14 B. and S. wire and still have difficulties with insulation even at almost double the Underwriters' specifications. It is particularly the case with bell wiring, which, though not so well insulated, continually requires repair. The interior communication system of the *New York* is now badly grounded after a carefully covered-in installation by the Cramps.

It is a curious fact that low voltage is a characteristic of all navies. We use 80 volts and it has been adopted by Great Britain. In other navies 65 volts is the more common pressure. While it would be perhaps more economical to use 250 volts, in view of increased motor use and commercial rating of machines, I hardly think it will ever be adopted, although we are now installing the new battle ships *Kentucky* and *Kearsage* at 160 volts, on the three wire system, preserving 80 volts at the lamps and connecting the motors across the outer mains.

As for conservatism in the naval service, I think it will be found that apparent delay in what is regarded as progress in electrical work is mainly attributable to a desire for the best obtainable product and standardizing it when found. In the vexed question of wire we have endeavored to introduce that which would be sound and acceptable as the best construction. We are now endeavoring to get a standard incandescent lamp and legalize candle power on the lines of good construction and careful test. Government appliances should in my opinion be a standard of reference, from up-to date scientific requirements, and, to ensure accuracy, the standard result must be obtained carefully, which necessitates time and experiment; and we should be slow to adopt apparatus which will subject us to well-grounded criticism on faults of specification. This must apply particularly to the adaptation of electricity to power when we must take the conditions of the ship where weight and space and vibration, together with insulation and water tightness, are no mean or lightly-to-be considered factors as regards the device and construction.

CAPT. JOHN MILLIS:—Although belonging to a branch of the service whose duties afloat are quite limited, I am much interested in this subject in a general way. There were three points that occurred to me concerning which I think Commander Greene can enlighten us. I understand that all these installations on board ship are direct current installations. Of course

we understand the limitations as to distances of transmission on board of a man-of-war, but it seems to me just possible that, in view of the peculiar conditions, it might be advantageous to make some applications of the alternating current system, or of the polyphase system on shipboard, and I should be very glad to have some points with reference to this suggestion.

As has already been brought out I understand that the questions involved are very largely in respect to getting very heavy weights in motion and of stopping them. That is, those considerations are of great importance in the handling of turrets, in ammunition hoists, in the steering gear to a certain extent, and perhaps in other applications with which I am not familiar. There is also the question of different voltages and of transformations, so that it seems to me possible that there might be some field for the alternating or polyphase system, although of course, in a form quite different from conditions ordinarily met with in commercial applications.

The second question is of a military nature and one which most of the gentlemen present are perhaps not very much interested in, but I recall seeing some reference to the use of searchlights at Santiago. I understand that in the operations there, the defensive use of searchlights was demonstrated, and it has even been said that Admiral Cervera's fleet did not come out at night on account of the confusion that it was subjected to by the searchlights of our own vessels lying outside. If that is correct, it will have an important bearing on our shore defenses, and the question arises as to whether it would not be advisable to install a large number of searchlights in these defenses, not only for the purpose of discovering the enemy—which is the principal object of the searchlight as it is now employed—but also for the special purpose of confusing him after he has been discovered.

The third point is in reference to the personnel on shipboard. We find in the military service a considerable difficulty in this matter. Unfortunately in time of peace men are not induced to enlist from patriotic considerations alone, and other considerations are not always specially inviting; and the line of promotion is not all that might be desired. The commercial demands for men who are skilled in a mechanical way or in an electrical way, are generally more inviting than anything that the military service offers, and the skill of the enlisted man is not always of the highest order. Possibly there is in the navy some more enlarged system of promotion, a larger number of non-commissioned or warrant positions, offering greater inducements for the enlisted men, which Commander Greene could enlighten us about. These considerations have a very important bearing on the questions which we are now dealing with in the military service.

Mr. H. L. Holbrow—In such an installation as Mr. Greene speaks of, the electric plant becomes a most vital portion of the

ship, and in the navy where the liability to damage or destruction is great, it might be advisable to duplicate the plant, each portion being in a distant part of the ship. This would not be necessary in the merchant service, however. Mr. Greene's estimate includes six machines. Should a division of the plant be decided upon, it would be good practice to place four machines in each portion. This would increase the weight by one-third. A rather undesirable feature.

Many of the gentlemen here this evening are perhaps not familiar with the personnel of the navy, and consequently do not know the kind of men that would be placed in charge of such a plant. I served in the navy as an electrician during the summer, and of course was brought into contact with many of these men. The apparatus aboard ship is managed by the gunners mates, who hold ratings as chief, first or second class petty officers, and receive salaries ranging from 35 to 55 dollars per month. They are trained for their work at the gunnery school, where I believe, they spend one year in studying the construction and handling of guns, and the management of dynamos. The greater part of this time is devoted to gunnery, so that very little can be devoted to the electrical portion of their work. Should one of these large plants be immediately installed, it would probably suffer for the want of trained management. However, as these changes will in my estimation be a matter of gradual development, the government will be able to train and supply men for this particular work as the occasion requires.

Mr. T. Commerford Martin:—There are various points in Lieut.-Commander Greene's paper which, it seems to me should not pass without some comment and possibly explanation. I was somewhat struck with the reference which Mr. Greene made to the inefficiency of telephonic service on board men-of-war. I must confess that that intimation comes to me somewhat in the nature of a surprise, just as the later intimation did of the failure of electric bells on board ship. It may possibly be due to the fact that this expert work in bell-wiring and telephony was done by the Cramps. I had not heard of them previously as particularly expert in that direction, as they are in others, and do not remember at any time having found it within my province to commend them for their skill in electrical work. It is possible that if this work were left to those who know something of bell wiring as such—I mean as an art. not merely as an industry to be accomplished at the lowest price possible that the work can be done for, and if the telephonic work were left in the hands of those who are competent to handle telephonic apparatus,—there might be better reports. It is possible, however, that Mr. Greene has been misinformed as to telephonic work on board ship, and this possibility is somewhat borne in upon me by a little experience of my own recently in pursuing an inquiry with regard to electric range finders. It was announced somewhat early in the

war, and soon after one or two of the actions or engagements had taken place, that the electric range finders were no good, that they had collapsed, they had failed, could not be worked. I immediately started out to get a little information upon that subject. It was somewhat difficult at that stage of the game; all those who had anything to do with it being still too busy fighting, and not yet writing magazine articles on the subject. I did all I could however, to find out whatever was possible from our fleet in Cuban waters, but not eliciting any information in that quarter, I wrote out to Manila, to my friend Bradley Fiske, told him what I had heard, and expressed, as I naturally would under those circumstances, my doubts as to the accuracy of the information. His heart warmed toward me, and he wrote back very fully on the subject, and said that so far as he had heard he did not know just where those things had been tried, and would like to know, and asked me to go on and investigate further. I did so until at last I landed somewhere in the Navy Department, and there is at my office a statement from one of the bureaus—I will not attempt to distinguish it—stating that as far as it knows, not a single electrical range finder was in service during the late war. Hence, it seems to me that the slight criticism which Mr. Greene conveys by that remark in his paper is hardly justifiable under the circumstances, and I venture to believe that if the inquiry could be pursued right down to the closest detail, we would find that telephones also are a pretty good thing on board ship, and that all that is needed is that the wiring shall be done expertly and properly, and that the wires, the bell wires for example, should not merely have the insulation which our friend Lieutenant Walling has described, but might possibly go through tubes which would more or less protect them from the action of salt water and sea air. The whole thing simmers down to the difficulty the navy has in retaining the men who have mastered the details of electrical appliances. They are not willing to stay in the service. If the navy could retain those men I think we should have great unanimity in the navy as to the desirability of electrical apparatus. But the trouble of it is the electrical men won't stay in the navy. We have a distinguished instance here on the platform to-night, and as long as the temptations for talent and ability are such as the larger field offers, I am sure nobody can blame them. We are all glad to have them on shore, although I did hear a man complain the other day that the naval men were getting all the large jobs, even down to the consultation of the Third Avenue Railroad.

One of the events of the late war in connection with the work of electrical apparatus, struck me particularly, and it is a field in which I think there is certainly room for improvement. After Admiral Dewey had sailed into Manila Bay and had presented Spain with the largest submarine fleet in existence, the cable being cut, we were absolutely at a loss; we could not com-

municate with that part of the world at all. Now, a navy that can cut a cable, certainly if it is worthy of the name, should have the ability to repair a cable when it is cut. I am sure that we must all have read with feelings of despair and indignation some of the proceedings off the coast of Cuba, when men-of-war's boats and launches and even larger ships, lay there exposed to the fire of the enemy which even once or twice did prove deadly and were sawing and see-sawing and hacking and chopping at those poor, unfortunate cables and trying to cut them; whereas one or two old cable men under the guidance of such an expert as we have on the platform in our President would probably have disposed of the job in a few minutes. It seems to me if we are going in for a navy, and if we are going in for expansion, the very first thing that our navy will have to do will be to provide itself with an equipment of that character. This little fact has very much impressed itself upon me in the last week when the navy decided that in order to protect our interests in the Philippines it would be necessary to connect the various islands together. As far as I am aware there is not a single man in the United States navy to-day who is in anywise competent to conduct or contral those operations, and the result is that we have to go to England, and I understand that English talent has already been hired by our navy to go out to Manila and do that work. I am glad to know that we are buying the cable in this country, but I believe that all the auxiliary apparatus, without exception, is being ordered by our navy to-day from England. Personally I am one who rejoices from the bottom of his heart over the Anglo-American alliance, and I like to see that we can depend on our good English friends for assistance of that character. But I should feel far more delighted if I knew that we could depend on our own resources for work of that kind in this country, and that such resources were at command in the service of our navy.

Mr. John W. Lieb, Jr.:—I think the figures which the speaker of the evening has presented to us, are of very great importance to central station men, particularly as the problems which they have to meet in the mechanical conduct of the stations are not altogether dissimilar to those met on board ship. The problem of electrically driven auxiliaries versus steam driven auxiliaries is of quite as pressing importance from the central station point of view as it is on board ship, and I think it would possibly cover a point not previously referred to, if one or more features connected with the difficulties of auxiliary drive by electricity were pointed out. In the tabulation we have before us, one advantage of steam drive certainly as applied to central station practice, probably also as applied to marine practice, does not appear. If from a central station, assuming it to be a condensing station with electrically driven auxiliaries, air in circulating pumps driven by electric motors, boiler feed pumps driven by electric motors, drip water pumps driven by electric

motors, an important problem arises—the heating of the feed water with the exhaust steam, and boiler feed pumps driven by steam. Where condensing apparatus is used, auxiliary feed water-heaters are available which are important in enabling the exhaust from the auxiliary steam driven apparatus to be utilized in heating the feed water. This is an important matter for every station, and I presume it would be the same case somewhere on board ship. Exhaust steam which returns to the boiler and from which part of the heat units in the steam used for steam drive, is not obtained from such sources; it must be provided for in another manner and at a considerable cost. This saving has not been mentioned as an element of advantage in the steam drive, and should certainly be brought forward in a full and fair presentation of both sides of the question. I would like to add one more point, and that is the point of flexibility of control. In such important elements as turret turning, the installation of systems, such as Mr. Leonard has described, become important, and the extra apparatus required and the additional expense, is warranted by the importance of the apparatus to be controlled, and also by the fact that units are small in number. But when it comes to controlling a number of pumps, electrically driven boiler feed pumps, air and circulating pumps, the difficulty of getting a sufficiently wide range by rheostat control or the limited control given by field rheostat becomes of very considerable importance; and where electric drive is reserved for boiler feed purposes, it is often necessary to run the pumps driven electrically at practically constant speed, and do the regulation by a steam driven pump; or when the electric unit becomes too large to handle the power plant at full load, it is necessary to resort to the steam driven pump to get a sufficiently wide range of regulation and control.

I was very much interested in the presentation by Prof. Thomson of his experiments in connection with the reduction of steam consumption in small steam motors. It is a subject which is extremely interesting to me, and while to discuss it thoroughly would lead me too far afield, I just wish to refer to certain observations which I had the opportunity of making last summer while on a trip abroad. The question of the use of superheated steam has passed from the stage of theoretic consideration to the stage of application in practice. Among the most prominent advocates in the use of superheated steam is Prof. Schmidt. The results that he has already obtained are surprising. I have seen tests conducted by German experts on similar engines of 50 and 60 horse power where the steam consumption is below ten pounds. Of course, in handling steam superheated 500° or 600° Fahr., new problems arise, which I will not undertake to discuss, but simply point out the novelty to some extent at least, we might call it, the novelty of the use of poppet valves for the steam admission, the point referred to by Prof. Thomson in his

discussion. No doubt the use of superheated steam will be a matter which we will hear much of in the very near future, as indicated by the enormous progress which has been made in its application abroad.

Capt. Millis:—If I may be pardoned for one word further—I think we are all ready to concede that the United States navy does not need any defense at this time, but the remarks which the gentleman made on the subject of cable cutting recalled to my mind the fact that I saw a section of one of those cables that were cut on the south shore of Cuba during the late war. The shore there is extremely bold, and great depths are found close into shore, The section I refer to was of shore cable. It was about 3¼ inches perhaps in diameter. It had a double armor of steel wires. The outside wires were nearly as thick through as one's little finger; and, although I am not prepared to state that the cut which I saw was the cut which they made, it is natural to suppose that they made the shortest and cleanest cut it was possible to make under the circumstances. I understand they grappled and raised that cable from a small boat. They were under fire, several of the men were wounded, and I think one or more were killed while they were hacking and sawing at this cable. They finally succeeded in getting it separated. I have had considerable experience in handling submarine cables of a good deal smaller size than that, but I never attempted to cut one under the fire of Mauser bullets, and I do not think that the most skilled civilian electrician not accustomed to military discipline could have done any better than those men under the circumstances.

With regard to the repair of the cable running to Manila, it is a military principle—I suppose also a naval principle—that means of communication with headquarters in case of operations of that kind are sometimes very necessary, and very valuable and very desirable. Under other circumstances it may be better to have the cable thoroughly and effectually cut.

Mr. T. Commerford Martin:—I hardly think that it needs any avowal from me that I would be the last, or certainly among the last, to reflect for one single instant in thought or word upon the glorious valor of the men who put themselves under fire to go through such an operation as that, and I know that had our friend Capt. Millis himself been there the operation would have been just as successful as it could be with the resources and experience which he has at his command. At the same time I would like to say that I have heard criticism and comment made both by officers in the navy and by those who are familiar with cable operations in the Atlantic upon the subject of that work, and they have united in saying that it was an unnecessary and needlessly long exposure of the men who were unfamiliar with such work, and which would have been much better done had cable maps and proper resources and trained men been at the

disposal of the officers commanding the squadron at that time. That was at least the point that I wished to make. I would like to emphasize what I have just stated in regard to electricity in the navy, and the fact that the men who know something about it should be in the navy, by saying I do believe that the remedy will come if one of the measures now before Congress happens to go through—that which looks to the unification of the line and the engineer officers. I think that is a step which we all look forward to with a great deal of hope, and which we trust will very shortly be accomplished.

MR. JOSEPH BIJUR:—There is one other point in connection with high voltage on board ship to which I should like to refer, that is, regarding the use of searchlights. As a rule a voltage is well adapted to searchlight operation when there is a drop of 25 to 35 volts between the generator and the arc. The arc is peculiar in being in unstable equilibrium, and its action is so rapid that its resistance either increases or decreases enormously before any mechanism can adjust itself to take care of it. To overcome this difficulty, it is customary to insert an external resistance between the generator and the carbon terminal. This acts as an automatic regulator, without any time element. The moment the resistance of the arc becomes less, owing to some increase of the current and consequently of the cross section of the arc, the voltage at the carbon terminals falls, because of the increased drop in the external resistance, and the current comes back to normal value. If, on the other hand, the resistance of the arc tends to rise because its cross-section was diminished by some decrease in the current, the voltage across the carbons rises correspondingly on account of less drop in the external resistance, and the arc re-establishes itself.

When you have a drop of 25 volts between generator and arc you have about the right amount of external resistance, to compensate for the changes of resistance in an arc, but when you come to get a drop of 110 or 150 volts between generator and arc you have entirely different conditions. Then, the regulating effect of the external resistance is too great, and the arc surges up and down slowly, and is a troublesome thing to deal with, and requires different mechanism for its regulation.

At any rate, very little work has been done in that line with large arcs, and there is a certain amount of experimental work that has to be done before searchlights can be successfully operated on those circuits. At least such has been the case with other arcs where no difficulty had been anticipated, but when they were put on high-voltage circuits and sufficient resistance put in series with them to bring the voltage across the terminals down to the proper point, the arc surged up and down in a very unsatisfactory manner, and considerable trouble was experienced. I mention this simply as tending to show that some experimental work must be done before introducing high voltages on board ship.

A Member:—In regard to the point made by one speaker as to the undesirability of using electric drive for auxiliaries, either for central station or on board ships, it seems to me there is a point there that is overlooked. If we can use electric auxiliaries and get the power to drive those for say 30 pounds of steam per brake horse-power as against 119 that it takes for the steam driven auxiliaries, we have got there a matter of 80 pounds of steam per horse-power hour, which we can use if we wish to, as live steam to heat our feed water. On the other hand, the only way of heating feed water is really to save some of the heat in the exhaust steam that we are wasting by using non-condensing pumps, so that we would be in better mechanical condition to use our steam in condensing steam engines and then heat our feed water in the boilers, or if we want to avoid the strain in the boilers, use a little of the extra live steam we are saving to heat our feed water, and still use the electrically driven auxiliaries.

Mr. Lieb:—The gentleman should not understand me to say that I was opposed to electrically driven auxiliaries. I simply wished to point out one difficulty in connection with their use which had not before been presented.

The President:—Is there any further discussion on the paper? If not, Mr. Greene will take up the various points that the speakers have stated.

Mr. S. Dana Greene:—I want to thank the members of the society for the evident interest they have taken in the paper as shown by the discussion which has followed, and which I can assure you has been most interesting to me. I have made notes of a number of points, and I think that some of the points raised have been perhaps due to a little misunderstanding. First, with reference to Prof. Thomson's remarks about the high possible economy of small simple steam engines, it might appear from what he left unsaid, more than from what he said, that his remarks were in contradiction of his statement that the electric drive was the only thing to use on board ship. It at once occurred to me, what no doubt Prof. Thomson had in mind, that the high steam pressures necessary to obtain these economies, makes this form of steam drive absolutely impracticable on board ship. I do not think any man who has had any experience afloat would question that statement for a moment.

Lieut. Walling, in referring to the improvement of the efficiency of certain small engines on board ship, gave, unintentionally, I think, an erroneous impression that the engines he spoke of included *all* the various auxiliaries; whereas I am quite sure that the particular engines to which he referred as having improved in economy were only those operating the electric generators. As I pointed out in the case of the *Minneapolis* there are between 30 and 40 auxiliary engines, and in a great many of them, as some other gentleman has already pointed out, the conditions of service are such that they must inevitably be un-

economical, giving a very low average economy as this test showed. I think Lieut. Walling has rather missed the point with respect to the anchor hoist or winch and the steering engines. It seems to me not a question of the reliability of the motor, but of the reliability of the *mechanical application* of the motor to the operating mechanism. I can illustrate this perhaps by reference to the experience on the great lakes in towing vessels. The introduction of the enormous barges carrying five or six thousand tons of ore has revolutionized towing, and the old-fashioned method, which still prevails on our coast, is laughed at on the lakes to-day. They found that the pitching, which is the condition Lieut. Walling spoke of, will snap any steel hawser. They now have a towing engine which automatically takes up the slack or pays out the hawser as the vessel pitches. I have seen tows of four and five of those vessels each carrying five or six thousand tons of ore in a heavy sea on the lakes, when the captain of an ordinary tow along our coast would have scuttled for harbor very quickly, leaving his tow adrift perhaps.

I also question the difficulty of insulating for 160 or 200 volts. I do not think we need consider that seriously. That is to say, I for one am not prepared to admit, nor do I think that any man who has had experience in wiring is prepared to admit, that a piece of wiring work on board ship or anywhere else cannot be installed to give a high insulation resistance for 200 volts. I think it is largely a mechanical question. A great many of the troubles in the wiring of ships, are due to mechanical injuries to the cable. By mechanical injuries I refer not only to cuts and abrasions, but to the rapid deterioration of the insulation due to heat or oil. We all know the effect of heat and oil on rubber insulation. My suggestion, as a remedy for this difficulty, made a number of years ago while still in the service, was to run a series of ducts fore and aft in the ship while building, with branches or "risers," in every compartment, using these ducts simply as runways for the wires. I think it would be a great protection if that were done.

Capt. Millis, I think, has suggested the possible use of alternating current apparatus on board ships, and I think that is quite possibly one of the developments of the future. One point which will have to be thoroughly worked out, is the control of induction motors under varying conditions of load and speed; a control which, as Mr. Leonard has very clearly pointed out, must be absolute and exceedingly fine. If I am not mistaken the *Brooklyn's* turrets have been started and stopped thirty times in 3 inches of arc.

LIEUT. WALLING:—Thirty-seven times in a minute.

MR. GREENE:—That gives you the idea of the fineness of the control. That is the whole secret of pointing guns. The man has got to feel that he has absolute control of his turret or his 8″ or 12″ gun; the nearer the gunner can handle it as he does a

rifle, automatically, so to speak, without having his eye distracted from his sights, the better shooting will be done.

With reference to searchlights, the point the gentleman last speaking made as to the arc not operating properly with a large resistance in circuit (on 160 or 200 volts circuit,) may be entirely correct. I confess I have not had experience on that point; but if it is true, my suggestion would be, not to sacrifice the rest of the plant, but to put in a separate machine for operating the searchlight. The searchlight circuits are run independently on board ship to-day. Install a separate machine for each of them; it would not need to be a large machine, nor would it have to be used very often. I quite agree with the suggestion that searchlights should be introduced largely in our coast fortifications, and as a matter of fact a great many were introduced during the late war. But the conditions of use of the searchlights at Santiago were very different from those which obtain, for instance, off Sandy Hook. At Santiago, ships on the outside were directing a beam on the entrance, not over a couple of hundred yards wide; maintaining it there and lighting up the entrance so brilliantly that vessels lying three or four miles on one side or the other of the beam of light could see a small boat distinctly at the harbor entrance. There is not the slightest doubt that if Admiral Cervera's fleet had attempted to come out at night, it would have been discovered by our fleet as quickly as it was when it came out in the daytime. It is one thing to put a searchlight beam on a stationary object, when we know where it is, and keep it there. It is quite another thing to pick up a moving object, particularly a small moving object painted a "war color," not knowing where to locate it. I think in almost every case where torpedo boats have made practice attacks on war vessels, the latter attempting to defend themselves by searchlights, the torpedo boats have won; in other words, they have been able to discharge a signal rocket within "torpedo distance" of the ship before they were discovered. It requires great practice, and I know from personal experience that it is very difficult, to pick up even a comparatively large vessel when you have got to look for her and do not know where she is, and you are sweeping the horizon with the arc. Therefore, I do not think too much stress should be placed on searchlights for shore work. Undoubtedly if the vessel is once discovered they are very useful in keeping her exposed as a target and in confusing those navigating the vessel.

The question of properly trained men for the navy is purely a business problem. If you are operating a large central station, using triple expansion engines and large direct coupled units, you expect to have a better man in charge than in the case of a small station with simple engines and belted generators. The navy cannot expect to secure good men in time of peace for routine work unless they pay for them; I think that they *can* secure a very excellent

class of men if they raise their wages on board ship, so that they are comparable, for instance, with those of first-class machinists who, if I am not mistaken, receive somewhere between $75 and $100 a month and their rations, with no rent to pay; Uncle Sam gives them their hammock-space free. The amount of knowledge and intelligence required of men to handle electrical apparatus on board ship is not excessive. Practical operating men are wanted; and if the navy is willing to pay for them, I have not the slighest doubt that they can be obtained and that they will remain in the service.

It seems to me that Mr. Lieb's point as to the question of using the exhaust steam from the steam auxiliaries for heating feed water is, as the gentleman has pointed out, entirely covered by my figures, if they are correct. If the saving which I have indicated by these figures (and I think that I have been conservative) is correct, then no possible saving, such as Mr. Lieb suggests, can make up for this difference. I think the same is true of the auxiliaries in a central station, though perhaps to a less degree, because the conditions of operation in a station are less severe than on board ship. I know of one station which has no steam cylinders outside of the main generating engines except a reserve steam feed pump, and I think that the economy of the station, including the auxiliaries, compares favorably with any other station in the country. Of course, the load factor cuts a very important figure in central station economy.

One gentleman has suggested that we should have duplicate plants on board ship. We might say the same thing of the boilers and the engines. I pointed out that if a plant for the auxiliaries is to be used on the scale suggested, we must consider it as one of the vitals of the ship, and it must be below the protective deck, just as the boilers, engines and magazines are. If it is so located, I think that the chances of its being disabled are certainly no greater than the chances of the engines or boilers being disabled. The present practice in the navy is, to allow about one-third reserve capacity; I do not think in a plant as large as the one suggested, 1,000 horse-power, it would be necessary to have so much. Possibly two spare units would be installed instead of one, as I have suggested.

I think there is a little misunderstanding on the part of both Mr. Martin and Capt. Millis as to the cable cutting off Cuba. I happened to see some of that myself. A regular cable steamer was for several days cruising off Santiago, trying to pick up a cable, and General Greely was cabling from Washington every day, wanting to know why it was not cut. The reason was that they could not find it, and the reason they could not find it was that the bottom was coral rock, covered with all sorts of tropical submarine growth; the cable was embedded within a mass of these coral rocks, and when it was finally raised it was found to be three or four times its normal size. Naturally this

cable steamer had to keep out of the range of the guns in the Morro Castle. She was grappling in 800 or 1,000 fathoms of water, although only three or four miles off the shore. That was a "professional" vessel with "professional" men on board. The men engaged in the cable cutting expeditions at Cienfuegos, as Capt. Millis pointed out, were obliged, in order to get the shore end of the cable to run in close to the beach, because the water deepens very rapidly there, as at Santiago. When the cable was once lifted and put on the rollers of the launch it was cut probably as quick as anybody could have cut it under the circumstances, and I think it was one of the pluckiest and bravest acts of the whole war. There was no excitement of battle about it; those men had to work under a steady fire from rifle pits, not 100 yards away.

Mr. Martin referred to my statement in reference to range finders and telephones. I was very careful about the language I used. I said there are devices, "like the range finder and telephone, which while of great utility, have not yet demonstrated that they can be relied upon at all times." I think the best demonstration of the truth of my statement is, that they were not used during the battles of Manila and Santiago. They are of great utility; we all know that, and all admit it. They were not used in battle to any extent because they were found not to be reliable or serviceable under these conditions. In the case of the telephone, it is not merely a question of the reliability of the instrument. A man may be stationed near a blower or near escaping steam, or among the many rattling noises on board ship, and any telephone is absolutely useless under such conditions. The telephones may be in perfect working order so far as their condition of electrical operation is concerned, but they cannot be used. The same way with the range finders. The range finders have to be placed at the end of a base line of known length on board ship; communication has to be maintained between these stations by telephone; not only between them but with the conning tower and the various indicators around the ship. I have no doubt that one reason why neither the telephone nor range finder were used more in those actions than they were, is because under certain conditions there is so much noise that it is absolutely impossible to hear the telephone at all. Perhaps sometime we shall have enclosed telephone booths aboard ship, as we have on shore, and then it can be used at any time.

THE PRESIDENT —I think that I shall be voicing the general feeling and sentiment of the meeting if I extend to Mr. Greene the thanks of the INSTITUTE for the paper that he has kindly brought before us. There is nothing further before the INSTITUTE, and a motion to adjourn will now be in order.

[Adjourned.]

[COMMUNICATED AFTER ADJOURNMENT BY MR. GEORGE HILL.]

Professor Elihu Thomson's discussion of Mr. S. Dana Greene's paper " Electricity on Board Ship" presented at the meeting of January 25th, 1899, calls for a comment on certain statements made, which in the opinion of the writer are not borne out by the facts. The intimation is made that a simple single acting non-condensing steam engine can be made by a slight change from the standard design as economical as a triple-expansion condensing engine. The principle of the change is indicated by Professor Thomson in the statement that "I must imitate the cycle of the gas engine in steam, and then I would get high efficiency with other advantages." The cycle of a gas engine as ordinarily understood is as follows:

The admission of a certain amount of mixed gas and air during the forward stroke of the piston; the compression of this gas and air during the returning stroke of the piston; the explosion of this compressed mixture at the instant that the piston begins to move forward, the sweeping out of the products of this explosion on the return stroke of the piston, and the drawing in of a new charge of gas and air with the forward stroke beginning a new cycle. The cycle therefore occupies two complete revolutions, one of which may be called a working revolution and the other an idle one. Nothing in the engine described by Professor Thomson approaches this. In describing the action of the engine he says "now instead of reversing the motion of our steam as it enters back of the piston and throwing it back to the heated surfaces in exhausting, we are careful never to throw it back, but always let it go forward." Such a statement seems very curious from so eminent a source; the steam must act expansively; as a consequence the entire cylinder is filled with steam during the entire forward stroke at a constantly decreasing pressure and consequently a decreasing temperature. When the return stroke begins, the cylinder is filled with steam at atmospheric pressure and this steam is compressed giving the compression line shown in Fig. 2. The entire cylinder being filled with steam of a given temperature at the point of release, it really makes no difference at which end of the cylinder the steam is withdrawn. As a consequence, the engine is no different in principle from the Westinghouse engine. The steam consumption per horse-power hour seems very low, and would be remarkable, if it were ordinary steam at 160 lbs. pressure without superheat, but Professor Thomson states that superheated steam is used, without stating the number of degrees of superheat, which accounts for the low water consumption. If he had expressed the efficiency of the engine in heat units actually utilized, or in pounds of coal of a stated composition per horse-power hour, the result would have appeared very different. The available heat in steam at 160 lbs. gauge pressure, expanded to atmospheric

pressure is 46 H. U. per pound, each degree of superheat adding to the available energy a considerable percentage, which percentage is greater than that due to an increase of one pound in pressure, but both require the expenditure of energy either by the consumption of coal or otherwise, and must be accounted for in stating the economy of the engine. Something too must be allowed for the fact that the engine tested was new, and probably a great deal of pains taken to eliminate all waste. In conclusion it would seem desirable to obtain much more data in regard to the engine and its operation before we flatter ourselves that any material advance has been made in steam engineering by either Professor Thomson or M. Serpollet.

New York, March 28th, 1899.

[A Reply by Prof. Elihu Thomson to Mr. Hill's comments on his discussion of Mr. S. D. Greene's paper on "Electricity on Board Ship."]

I am too busy to enter into a lengthy discussion with Mr. Hill on the points raised by him, but will venture, for the present, the following remarks:

My comments following Mr. Greene's paper were made offhand, and were not prepared in advance. They had necessarily to be brief, and nearly as possible to the point. I certainly did not intend to indicate that the best results of triple expansion engine practice were likely to be excelled by the simple form of engine which I described. But that the effects of simple engines could be made to approach more nearly the highly economical results of more complex types is evident when it is borne in mind that our simple engine of only five and a fraction horsepower, in reality composed of four simple engines of little over one H.P. each, when tested, gave results in water consumption not greatly differing from those of tests of engines of hundreds of horse-power in compound condensing types. A factor in the cost of power is interest, wear and tear and depreciation, which are manifestly the less, the simpler and cheaper the engine, other things being equal. Mr. Hill finds fault with my comparison of the cycle of the small engine with that of a gas engine, seemingly ignoring those types of single cylinder gas engine which make one explosion every revolution. He must admit, however, that in the simple engine, an action is produced every revolution which in the type of gas engine he selects for comparison is only produced for every other revolution, and that in consequence the simple steam engine described has the advantage of less friction and negative work. Besides, I was speaking only in general terms when I referred to the gas engine

cycle, and merely as an assistance to the understanding of the actions in the simpler engine itself.

We have indeed to be thankful that:—"Nothing in the engine described by Prof. Thomson approaches" the *idle* revolution of the four stroke cycle of the gas engine. I am surprised at Mr. Hill's not understanding what was meant by the statement I made in the words; "throwing it back to the heated surfaces in exhausting," etc. He has totally missed the significance of the words "*in exhausting.*" Does he find that the steam goes back to the hot end and out of that end *in exhausting?* It does go back (what amount is left of it) *in compressing.* This is so plainly evident as to need no discussion, and it is certainly not a bad feature. It is not a wasteful process, surely.

Does Mr. Hill really think, and can he truthfully maintain that "it makes no difference at which end of the cylinder the steam is withdrawn? If one end is hot, as heated by the incoming steam at high pressure, is it economical to discharge steam, *cooled* by expansion and delivery of energy to the moving piston, at the hot end, and so allow the steam in exhausting to run away with useful heat? What a beautifully wasteful process is that which involves the admission of steam between or over surfaces which have just been bathed in cool steam (and perhaps condensed water) leaving the cylinder. I freely admit that the fact of the use of superheated steam, has perhaps something to do with the low water consumption shown by repeated tests, and preparations are being made to test a much larger engine of the same type, with steam in all degrees of humidity, dryness and superheat.

As I was testing *an engine* and not *a boiler*, I rather preferred to exclude the boiler from the tests, particularly as no means were at hand to do differently. Just why this was the case I cannot stop to explain now. It is true that to obtain hot, dry steam, may mean the communication of more heat units per pound of steam than in the case of wet steam or saturated vapor, but the difference is comparatively slight. The change of state involved in boiling the water is, as Mr. Hill must know, the chief factor in the case, whether the steam be produced in one condition or another.

I cannot admit that: "A great deal of pains was taken to eliminate all waste." The engine was in good condition, of course, but not exceptionally so. Its simple construction permits of relatively easy maintenance. When I made the engine I expected to realize a result of about 30 pounds of dry steam per brake horse-power hour, which in itself would have been roughly about twice as economical a result as is shown in the best tests of such very small engines, of which I was able to obtain any data. I was skeptical of the result of the first tests, and freely expressed my doubts, but by going over the work and watching it personally, while insisting that everything be done to have the

errors count against the engine rather than in favor of it, I became convinced that my expectations had been greatly exceeded, and that a result of 20 pounds per horse-power hour, or slightly better than that, had been in fact, obtained, as I have indicated.

It remains to finish and test an engine of larger capacity and to do it under such varied conditions as will be likely to point out the relative values of those features which undoubtedly contribute to the still lower consumption which will probably be obtained.

The small engine tested was designed for automobile work, it being regarded as extremely desirable that but little water and fuel be carried, and but little steam escape during work. The clearance is great and the manner of exhaust and admission such that no trouble is ever experienced with condensed water in starting.

The engine is now in use upon a steam automobile, having a coil-pipe boiler heated by ordinary kerosene. It runs satisfactorily even under the very extreme condition adopted in some experiments with it, of a steam supply-pipe at a bright red heat. But this is, of course, abnormal and only indicates the wide range in character of steam which is permissible. That it is not injured by excessive heat in the steam supplied, is due, doubtless, to the poppet valve admission and the extremely early cut-off which permits the entrance of only a momentary puff of hot steam when the piston is full in.

As a matter of interest in this connection I would conclude by calling attention to the fact that Ewing in his work on "The Steam Engine, and other Heat Engines," on pages 160 and 161 gives some results of tests by Willans on a small, simple, non-condensing single-cylinder engine, in which, with 172 pounds of steam, an indicated horse-power hour was obtainable with 18½ lbs. of steam. This represents, as Ewing points out, an efficiency of 75 per cent. of the theoretical efficiency of an engine working under the conditions. Ewing also refers in this connection to "*Min. Pro. Inst. C. E.*, vol. xiii., part 3, and vol. xcvi., part 2," in a foot note.

Lynn, Mass., April 5th, 1899.

AMERICAN INSTITUTE OF ELECTRICAL ENGINEERS.

New York, February 15th, 1899.

The 132d meeting of the INSTITUTE was held this date at 12 West 31st street, and was called to order by President Kennelly at 8:10 P. M. The President requested the Secretary to make the customary announcements:

THE SECRETARY:—At the meeting of the Executive Committee this afternoon the following associate members were elected:

Name.	Address.	Endorsed by
ADAMS, FRANK PIERCE	Electrician, Stockton Gas & Electric Co., residence, 171 N. El Dorado St., Stockton, Cal.	J. A. Lighthipe. C. E. Sedgwick. Geo. P. Low.
ADAMS, JULIUS LE ROY	Chief Engineer, Hartford, Manchester & Rockville Tramway Co., Manchester, Conn.	Oberlin Smith. M. J. Wightman. Ralph W. Pope.
BROWD, PAUL K.	Chief Engineer, The Russian Electric Company, "Union" St. Petersburg, Russia	L. B. Stillwell. Edw. L. Nichols. H. J. Ryan.
CURRIE, N. M.	Superintendent, The Municipal Electric Light Plant, Conneaut, Ohio.	A. L. Hadley. E. A. Barnes. F. S. Hunting.
CODMAN, JOHN STURGES	Consulting Engineer, Associated with R. S. Hale, 31 Milk St., residence, 57 Marlborough St., Boston, Mass.	Chas. R. Cross. H. V. Hayes. W. L. Puffer.
DUNN, CLIFFORD E.	Patent Attorney, 229 Broadway, New York City, residence, 12-a Monroe St., Brooklyn, N. Y.	Chas. A. Terry. Henry Schreiter. Ralph W. Pope.
HUTTON, CHAS. WILLIAM	Chief Electrician, Sacramento Electric Gas and Railway Co., Sacramento, Cal.	J. A. Lighthipe. C. E. Sedgwick. F. A. C. Perrine.
SCHWEITZER, EDMUND OSCAR,	Electrical Inspector, Chicago Edison Co., 139 Adams St., residence 1906 Oakdale Avenue, Chicago, Ill.	W. E. Goldsborough C. P. Matthews. J. J. Flather.
TRUESDELL, ARTHUR E.	Assistant to General Superintendent, Peoples Light and Power Co., 443 4th Ave. Newark N. J.	Chas. R. Cross. Paul Spencer. Peter Wright.

WATERMAN, MARCUS B.	Electrical Engineer, Brewster Engineering Co., New York City, residence, 177 Lefferts Place, Brooklyn, N. Y.	Samuel Sheldon. Aug. Treadwell Jr. Douglass Burnett.
WISE, JOHN SHREEVE, JR.,	Electrician The Pa. Mfg. Light and Power Co., residence, 2023 Mt. Vernon St., Philadelphia, Pa.	J. H. Vail. A. E. Winchester. H. T. Hartman.

Total 11.

The following named associate was transferred to full membership.

Approved by Board of Examiners, January 13th, 1899.

GEORGE T. HANCHETT, Electrical and Technical Engineer, 123 Liberty Street, New York.

The following paper on Storage Batteries and Railway Power Stations was then read by Mr. Robert McA. Lloyd.

A Paper presented at the 132d Meeting of the American Institute of Electrical Engineers, New York, President Kennelly in the Chair: and Chicago, Local Honorary Secretary Pierce, in the Chair, February 15th, 1899.

STORAGE BATTERIES AND RAILWAY POWER STATIONS.

BY ROBERT MC A. LLOYD.

A difficulty confronting us is that very few operators of railway power stations have any data showing what they are doing. Electric light managers seem to take more interest in the output of their stations, and in many cases maintain a system of records of work done, but the manager of a trolley road is usually contented with superficial observations of the switch-board and the comforting fact that the cars are running.

We always find these managers greatly surprised when the actual state of affairs is shown to them on paper, and I believe that this INSTITUTE would be astonished at the results of a thorough research into the load curves of the railway plants of the entire country. You are of course prepared for the statement that the average load on a railway power station for a given period is much less than the maximum load occurring during that period and much more than the minimum, but it is not generally understood that the maximum load for the same period is apt to be far below the capacity of the generating plant in operation. As an illustration of this fact I show in Fig. 1 some data on a typical railway plant when 35 cars were running. We have not discovered any railway plant where this is not true, and I believe that the data on most of the railway plants of this country will confirm my statement. The first explanation of this would be that such a surplus capacity is necessary for reserve to meet emergencies, but I do not find it to be a useful reserve, and

shall refer particularly to Fig. 1, taking this station because from the standpoint of the manager, engineers and attendants it is dangerously overloaded, and has no reserve. In fact it was necessary to add to the capacity at once to make it safely operative.

I obtained these data on the day of heaviest travel in the whole year. It will be noticed that the highest point reached was within the capacity of the main station, and yet it was necessary to start up an auxiliary station. The central solid line shows the average load, and the upper and lower lines show the limits of the fluctuations occurring from moment to moment. The method pursued in getting these curves was to divide the day into half hours, and during the first five minutes of each half hour take the highest and lowest ammeter reading in each minute; these readings are plotted in the upper and lower curves; also to take ammeter readings every five seconds and obtain the average of these readings as the point in the curve of averages. Another convenient method of obtaining the curve of averages is by wattmeter readings. Among some of the interesting features in this diagram may be noticed the fact that the nominal capacity of the generating apparatus was about 400 K. W. in excess of its maximum output occuring at about 8 o'clock in the evening, and that the average output at this time was about two-thirds of the maximum. The excess of nominal capacity was not so great at 7 o'clock in the morning, or two in the afternoon when other high points occurred, but as it was known that the morning peak would be of short duration, the engineer decided to run through it without the auxiliary station, and in the afternoon the load increased more rapidly than was expected, and the auxiliary was not ready to go into operation on short notice, consequently obliging the main station to groan under a dangerous load for an hour or so.

It will doubtless occur to some that this station apparatus has been overrated, or that the engineer was incapable, or over cautious, but the fact remains that similar data are obtained in very many stations, and that in many cases the apparatus has been subjected to satisfactory tests before acceptance by the purchasers. It may be possible to build engines which regulate at all conditions of load and at the same time use steam satisfactorily at maximum load, but I do not find such engines commonly in

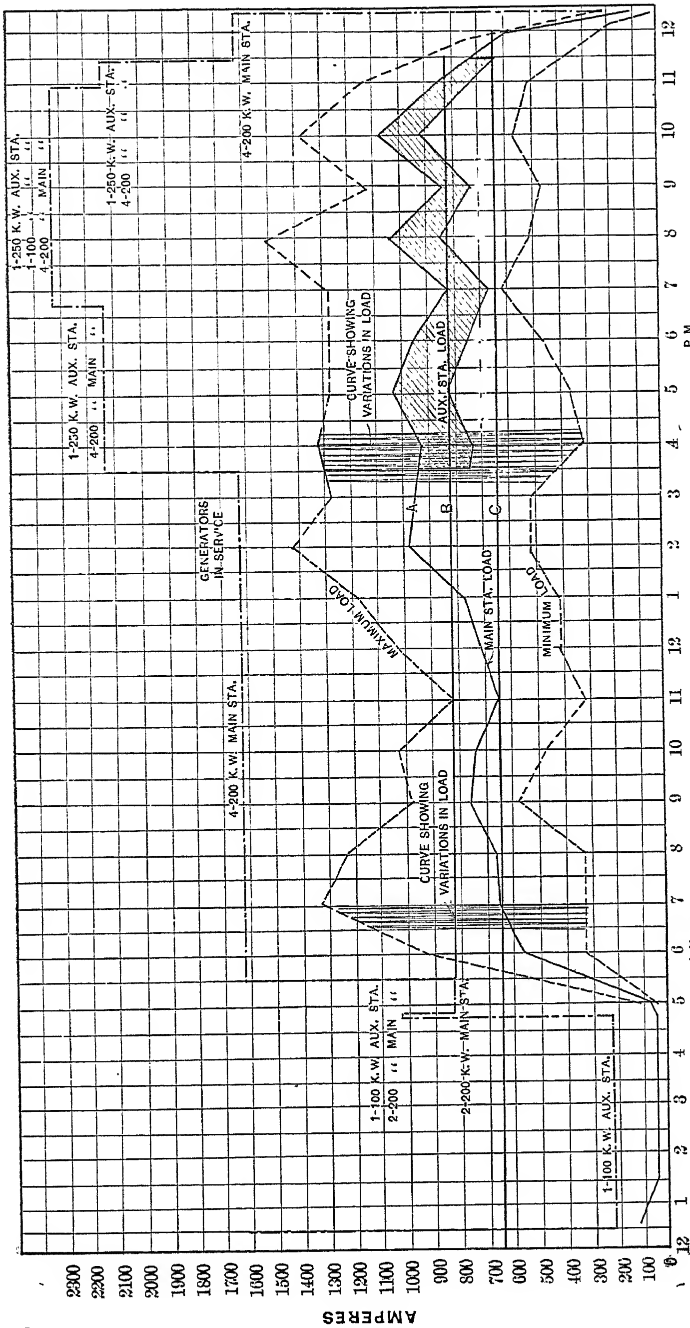


FIG. 1.—Curves showing variation of special Saturday load, August 20th, 1898.

use. Further than this there are many very good engines in use which cannot be safely operated at anything like maximum load if that load is liable to sudden variations. I realize that you may suggest all sorts of schemes for getting a better output from the plant illustrated by this curve, and you may wish to ask some questions about this apparatus, but experience convinces me that the men who are most likely to be consulted about such a station will recommend more generating plant, and the truth is that there are so many good salesmen pushing engines and dynamos that station managers frequently fail to get full duty from the machinery which they are operating already. It is not merely that the storage battery has been neglected, but any of us can see in railway power-houses throughout the country, where the managers have been persuaded to increase their generating plant, when attention to a few details such as steam piping would have brought their output up to requirements. Assuming however a station equipped with the best obtainable apparatus, and operated under the most advanced laws of station practice, in the absence of a storage battery, there would still be much more apparatus running than would appear necessary from the load diagrams.

The generator salesman says in reply to this proposition that his apparatus is cheap, and that it is good to have plenty of it, but one generally finds that where there is plenty of apparatus available, the engineer is tempted to keep too much of it running, and therefore running at low efficiency.

Of course railway power stations have individual characteristics, and it will not do to assume that they all need storage batteries, but there are certain features of railway power requirement, which are common to the problem everywhere, and which invite consideration for the storage battery.

The curve characteristics of electric light supply are well known, and much information about electric lighting has been brought out in the committee reports of the *National Electric Light Association* for 1896 and 1897, and by Mr. Hammond in his paper before the British *Institution of Electrical Engineers* in March, 1898, but the possibilities are more varied in railway work, and as far as I know, there has yet been no systematic research into the economy of railway power stations, the only published data on the subject being contained in the paper read before the Street Railway Convention at Boston last September by Mr. R. W. Conant.

In my endeavor to point out some of the uses for a storage battery, I shall take as a typical station that shown in Fig. 1. It is located in a Pennsylvania town of 50,000 inhabitants. The railways radiate from the center of the town to distances of three to nine miles. There are six branches, and the power station is located two miles out on the longest branch. It has railroad and water frontage. The small auxiliary power-house is the result of a recent consolidation and is close to the main house. There are three distinct ways of using a storage battery with this power plant. Taking up the figure we find first the great fluctuation between night and day load; second by the fluctuations occurring from hour to hour; and lastly the superimposed fluctuations occurring from moment to moment. We shall call a battery of sufficient capacity to level off the night and day fluctuations "large"; a battery for leveling the hour to hour fluctuations "medium"; and a battery to level the momentary fluctuations "small." It will be seen at a glance that the small battery will reduce the requirements of the generating plant to a capacity sufficient to meet the demands of the average load shown in curve A. The battery must be able to discharge at 650 amperes for momentary periods, but its capacity in ampere hours is unimportant. It will cost less than generating capacity for the same work, and a large part of the excess of capacity over requirements shown in the diagram will be saved. It will save some depreciation on the generating apparatus, and its own depreciation will not cost more than the depreciation of generating apparatus of similar capacity. It will have sufficient storage capacity to run a few night cars and lights, when the engines are shut down. If located at a point nearer the center of feeder distribution than the location of the generating station, a saving in copper will be effected. Inasmuch as the investment will not be increased by including such a battery in this railway outfit, all the saving in fuel due to a steadier load and the operation of less generating machinery will be clear gain to the credit of the battery.

Line B at 810 amperes shows the average load for 18 hours of the day, and a "medium" battery to reduce the load to this straight line would have a capacity of 1300 ampere hours. It will cost about twice as much as a "small" battery, but will not add enough to the cost of the installation to bring the investment up to the total now in generating apparatus alone, and presum-

ably necessary if no battery is used. This battery will have all the advantages of the small plant with wider limits of operation. The station circuit breakers may be set 650 amperes higher, and there will be greater convenience throughout the station in operating at a fixed load. There will be a marked effect on the efficiency of all departments of the station, and all the apparatus will yield a higher output in proportion to investment and cost of operation.

Line C at 650 amperes shows the average load for 24 hours, and a "large" battery capable of leveling off this load will have a capacity of 3000 ampere-hours. It will cost approximately twice as much as the "medium" battery and will have all of its advantages. It will cost as much as the generating machinery displaced by it. It will add largely to the flexibility of the station. This battery could be discharged momentarily at 3000 amperes, which will put the circuit breaker limit of the station at about 3600 amperes instead of 2300 with all the present apparatus. It may be discharged at 1500 amperes for one hour which will be sufficient to cover load peaks that would stall the 1150 K.W. generating plant completely.

In cases of extreme necessity the entire system might be carried by this battery for several hours. The ability to carry sharp peaks is a distinct addition to the earning power of the system. Such peaks often signify the collection of fares which would be lost if the system were not flexible, and some managers keep up enough station capacity to carry a few holiday crowds while for 99% of the whole year it is earning nothing. Other managers do not attempt to carry special crowds. The large battery will give the manager an opportunity to get all the money that can be made out of such business without feeling that he has made any investment for the purpose. Of course the capacity of the system is limited also by the investment in copper, but in many cases the battery may be located so as to facilitate the distribution of power.

There is no reason why a railway power station of this capacity running night and day at a constant load should not attain a fuel economy as high as that of the well-known Chestnut Hill Pumping Station at Boston which would be equivalent in electrical work to 557 watt-hours per pound of coal. Curve A, Fig. 1, shows for 1 days work 7,800,000 watt-hours which required at the above rate 7 tons of coal, and assuming that the battery

would only have 75% efficiency, and that 25% of the entire day's work would go through the battery, ½ ton of coal would be added to this consumption, making 7½ tons of coal per day for this plant running with a large battery.

The battery efficiency in such service as this has been found in most cases much higher than 75%, and in some cases over 90%, so my estimate is clearly on the safe side.

On the day when these data were obtained 15 tons of coal were burned, or twice as much as would be necessary with the battery outfit. The battery would therefore save at $2.00 a ton, $5,474.00 per annum in coal alone.

The number of men in the station is now the same night and day, and there would certainly be no increase in the labor item, whereas it is probable that one man on each shift might be dispensed with if the plant were reduced by the battery, in which case there would be another saving of $1,200 per annum. The battery would also save water, oil, waste etc., and there would be minor advantages such as more constant potential on the line; less annoyance from circuit breakers; no fear of sudden demands on the generating apparatus, and the disagreeable possibilities incident thereto.

In the following table some figures are tabulated for the purpose of comparing four different layouts to meet the requirements of the railway system referred to in Fig. 1.

TABLE REFERRING TO FIG. 1.

	Lay out with	Cost of generating apparatus	Cost of Storage Battery	total cost of station plant.	Cost of Coal per day	Cost of Coal per annum	Saving in Coal	Saving in coal and saving in int. 5 p.c.
1	No battery	$115,000	$	$115,000	$30	$10,950	$	$
2	Small Battery	60,000	20,000	80,000	25	9,125	1,825	3,575
3	Medium "	50,000	35,000	85,000	20	7,300	3,650	5,150
4	Large "	40,000	70,000	110,000	15	5,475	5,475	5,525

CONTINUATION OF TABLE.

	Cost of Real Estate and Buildings.	Repairs and Depreciation	Saving in Labor per annum.	Saving in water, oil, waste, etc.,	Total Saving	Estimated Addition to receipts.	Net Advantage in operation
1	All the same	All the same		$	$	$	$
2				100	3,675		3,675
3				200	5,350	1,000	6,350
4			$1,200	300	7,025	5,000	12,025

I have assumed $100 per kilowatt as the cost of complete station apparatus without batteries. This figure might have seemed high a year ago but in view of the rising prices of such material I think it is only conservative.

In regard to the "small" battery, there is no doubt of its advantages in many cases, but for new installations it is not always the most economical battery. I understand that Mr. Leslie Carter, the President of the South Side Elevated Railroad Co. in Chicago, said recently, that as far as he knew, their battery did not save anything in the cost of operating the road, but that they could not run without it, and I take the liberty of making the following extract from his annual report to the stockholders which has since been published.

STORAGE BATTERIES.

"While the amount of current used per car mile is low, and has produced gratifying results in all tests and comparisons made, the fluctuations of power above the average requirements are large, and the sudden demands on the power-house compelled us to prepare promptly for the heavier business of the winter, which, with increased number of cars in service, heat and light, loads, would have been beyond the capacity of the power-house. Additional engine capacity could not be obtained in the time at our disposal, would have cost more money, and have been expensive to operate. We accordingly installed two batteries of 750 K.W. each, equidistant from the power-house, at Twelfth and Sixty-First streets, respectively. These batteries have greatly reduced the fluctuations and the maximum load at the power-house. While the output at the power-house is the same, the batteries charge at times of light traffic and discharge at times of heavy traffic, thus equalizing the work at the power-house, and relieving the engines and generators. This is certainly an economy, and it is further claimed, with what correctness I am not yet convinced, that they cheapen the cost of production. But I do know that they keep up the voltage at the ends of the line, enable your road to operate more cars, furnish increased facilities to patrons, and prevent damage to power-house machinery in case of sudden demand for increased power."

That battery was of course put in for regulating purposes only, and the load curves some of which are shown in the following figures give one the impression that the battery must certainly be useful. It seems to me hardly worth while in laying out a new station to put in a battery for the purpose of reducing the rail way power curve to the characteristics of electric light practice, when by going a few steps further it may be refined to a practice comparable with marine engineering.

It might appear at first thought that a battery of sufficient capacity to ensure a full load for the generating units at all times, would save as much fuel as a battery large enough to level off the 24-hour service, but it is very difficult to follow the power requirements from hour to hour in such a way as to make ideal use of a battery, whereas with a "large" battery it would be possible for the ordinary station engineer to adjust his load so as to operate all of his apparatus to the best advantage all the time.

I have carefully analyzed the figures in Mr. Conant's very interesting paper above referred to, and am compelled to differ from him at some points, and refer to them in order to meet in advance any criticism of my paper which may be based on his tables. In the first place he assumes that his standard station can be worked all the year round with a load factor of $33\frac{1}{3}\%$ which is entirely too high: 20% or 25% would be more normal. I suspect that Mr. Conant's load factors have been obtained by indicator cards instead of wattmeters. In Mr. Conant's table none of the stations show a better figure for coal than 3 pounds per kilowatt hour while his standard station is put down for 2.2 pounds without any intimation of the process for attaining such a good result. The question as to how the cost of repairs and depreciation of the entire plant would be affected by a large battery is particularly debatable ground. Mr. Conant allows 2% for depreciation beyond the normal running repairs. He estimates the entire plant including buildings to last 50 years. His statement that the machinery now being installed will last much longer than that with which we have been familiar in the last decade has nothing to back it up except faith in the promises of the builders.

I propose to allow 10% per annum for repairs and depreciation, on the entire station apparatus, including batteries. I have not seen any boilers that are likely to last 50 years, and there is plenty of evidence that all the best engines and boilers in this class of service to-day will go to pieces in a life of from 10 to 20 years. The particularly hard usage to which most of them are subject is not only steadily wearing them out, but producing a state of constant danger and not infrequent accidents. I am sure this is becoming well understood among railway men, and some of the best managers are writing off to depreciation 10% per annum. Moreover who can say that improvements will not be made in the next 10 years as in the past, and that engines and boilers may not be out of date before they are used up.

It is of course well known that whatever the rate of depreciation may be without batteries, it will be lowered by giving the generating apparatus a constant load ; my belief is therefore that the storage battery will not increase the rate of depreciation for the entire plant. If it can be shown that interest and depreciation for a plant of given load dimensions are practically equal with or without a large battery, it is evident that the great saving in fuel alone will determine the superiority of the battery system.

I have so far considered the battery only at the central generating station, so that all the advantages due to locating it at proper points in the distribution system are additional arguments in its favor. In many cases the saving in copper may be greater than the sum invested in the battery, and the flexibility of the system improved in places where it would not pay to install sufficient copper to meet the irregular demands of travel.

The reserve qualities of the storage battery are unique. It might be supposed that a mere reservoir which is quickly drained would be of little value compared to a lot of extra generating apparatus standing idle, but experience is demonstrating every day in existing plants, that the reserve which is needed most is the reserve which is not only ready for emergencies, but actually alive to any demand without the direction of a human mind.

Most of what has been said of the storage battery as applied to the power station illustrated by the curves in Fig. 1, is true of its application to railway power stations in general. The use of water power introduces a factor in the problem more variable than fuel, and I shall not attempt the discussion of it. Alternating currents lend themselves readily to the development of storage battery applications on account of the mutually helpful combination of battery and rotary at sub-stations. Up to the present time, each of the large batteries installed for railway work has been obliged to meet different conditions, and requirements, but they are all serving their respective purposes well, and showing many different fields of usefulness. I shall not refer to these plants because Mr. Appleton in a recent lecture to the *New York Electrical Society* has ably described those of most importance.

Most of us feel that the electric railway and electric lighting interests are destined to get into closer relations, and the generating station of the future may be required to furnish all the electricity used within large areas for every purpose.

Coming finally to a problem which has been the subject of some newspaper discussion of late, I trust you will pardon me for treating of work with which I have no connection. Electricity has so many advantages over any other medium for transmission and storage of energy that I assume its use to be firmly established and cannot conceive of any lasting rivalry by the other contestants now in the same fields. Further than this without saying anything for or against monopolies, I believe that all the energy supplied by means of electric currents to consumers of every nature in the greater New York should radiate from two or three central stations, and that these should be electrically tied together. The sub-stations would naturally consist of rotaries and storage batteries. It may not be possible to lay out each substation so that the rotaries would run at a constant load for 24 hours a day, but it seems to me quite probable that such an arrangement would eventually be reached, and this would of course give the generating stations a constant load.

At the present time the load curves of the electric railways are very uncertain, and peaks are likely to occur at almost any time of day, while the addition of the peak due to electric lighting in the early evening would not add in large proportion to the railway peak, but electric lighting is capable of more general application and it is possible that within a few years the distribution in the Borough of Manhattan may reach from three to five hundred thousand kilowatts at the highest part of the lighting curve, which will probably be as great as the railway load when the elevated railway and the underground rapid transit are included. These peaks will often occur at the same time of day, and so there is no possibility of improving the load factor of either system by splicing the two together. It follows therefore that what is true of the relation of a storage battery to the economy of the generating station for power or light separately will be true of the resultant of their combination.

The railway and light people recognize the importance of leveling up some portions of their load curves, but I estimate that the greatest saving is to be obtained by operating for a constant load 24 hours per day. However high would be the economy of such large stations I am sure it would be higher with large batteries than without. Certainly the economy of the Boston pumping station as to fuel consumption should be surpassed. It must not be assumed that a high load factor for the system is

an advantage. It is all right for the generating plant and for the copper feeders, but the kilowatt hours that bring in the most money, may spoil the looks of the load diagrams and kill the load factor. What is required to earn dividends is a *profitable* load factor outside of the stations, whether high or low, and the highest possible load factor at the dynamo terminals. The large storage battery meets these two requirements perfectly. A load factor of 100% may be maintained at the dynamo and current may be sold to the consumer regardless of the time of day.

With a million kilowatts in view for the Borough of Manhattan it would be necessary to generate an approximately constant force of 300,000 kilowatts.

A million kilowatts in station plant without the battery factor would cost $100,000,000.

The same capacity including the proportion of battery now deemed advantageous by some of the engineers in touch with these problems would be divided as to cost into $70,000,000 of generating plant and $30,000,000 of battery plant.

Finally the same capacity if divided in the proportions which seem to me most productive for the investment would cost $30,000,000 in generating plant and $70,000,000 in battery.

This is quite a large battery plant and as there would be more than two parts battery to one part generator, I am fearful of the jealousy which such a reversal of engineering practice would create.

In conclusion I wish to state that nothing in this paper should be regarded as emanating officially or unofficially from the company with which I am connected.

The following figures show a number of railway power curves with and without batteries. If they do not indicate attainment of perfect results by the battery, it is not because perfect regulation is impossible, but because the engineer is well pleased with what he has, and does not strive for greater refinement. Fig. 2 shows the application of storage batteries to a large rail way installation in which part of the power is generated at a waterfall. It shows what may be done by what I have called a "medium" battery.

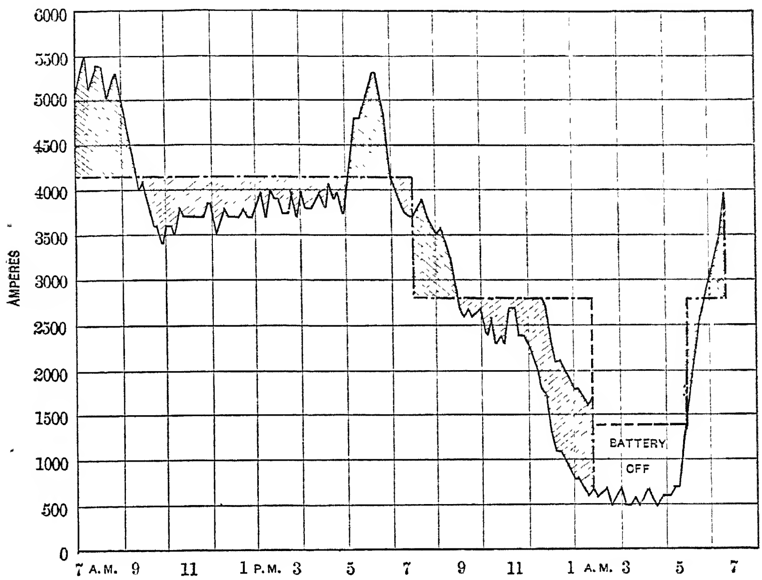


FIG. 2.

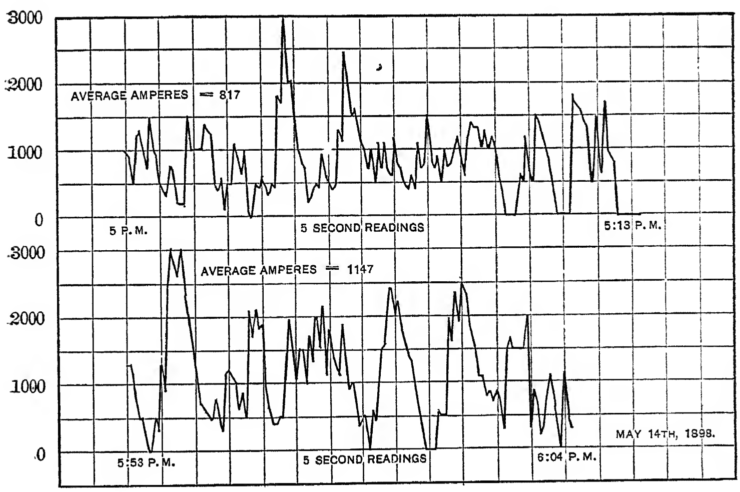


FIG. 3.—Curves showing Fluctuation of Load, May 2d, 1898, at Power Station of South Side Elevated R. R. Co., Chicago, Ill.

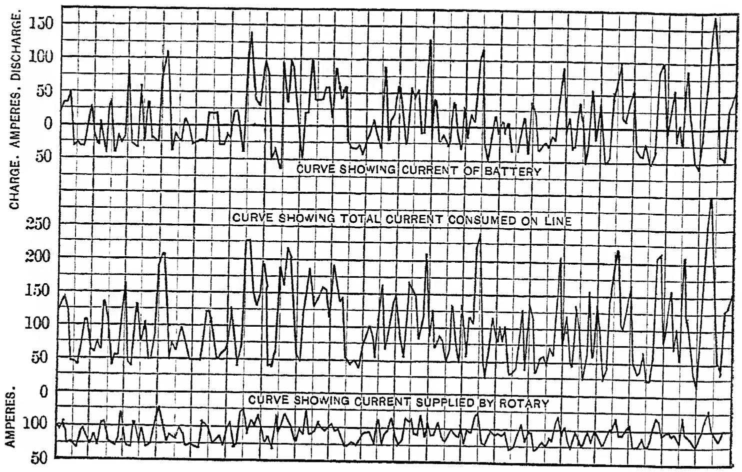


FIG. 4.—Curves showing Regulating Effect of Storage Battery, at Power Plant of the Barre, Montpelier Traction Co., Montpelier, Vt.

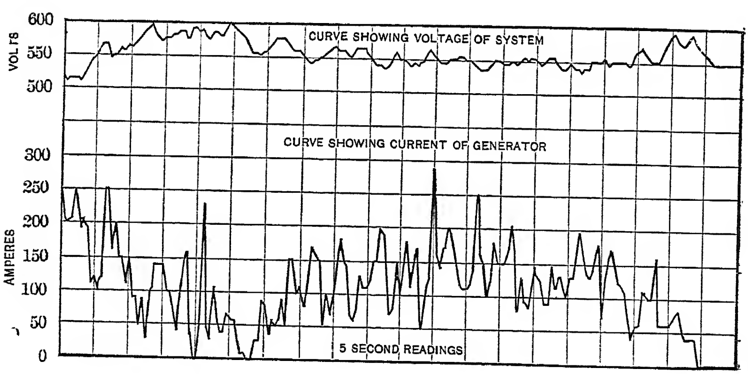
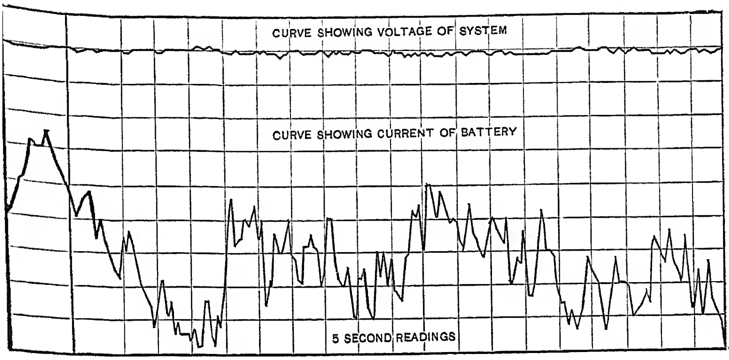
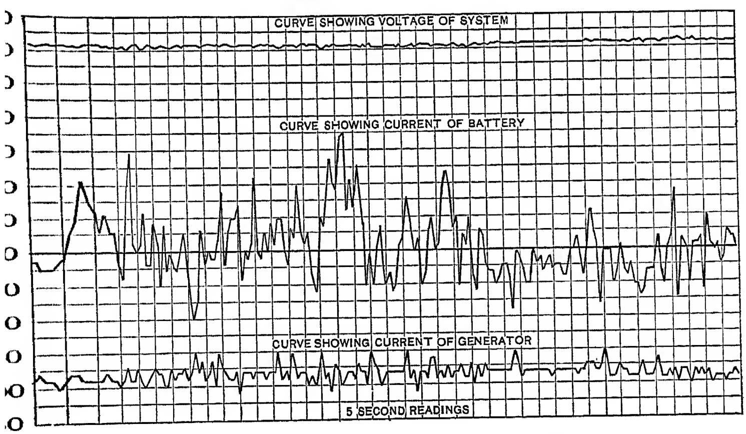


FIG. 5.—Tests made at the Woonsocket Electric Machine and Power Co. Generator carries the whole load of station. Barber Regulation.



G. 6.—Tests made at the Woonsocket Electric Machine and Power Co. Battery carries the whole load of Station.



IG. 7.—Test made at the Woonsocket Electric Machine and Power Co. Generator and Battery in operation.

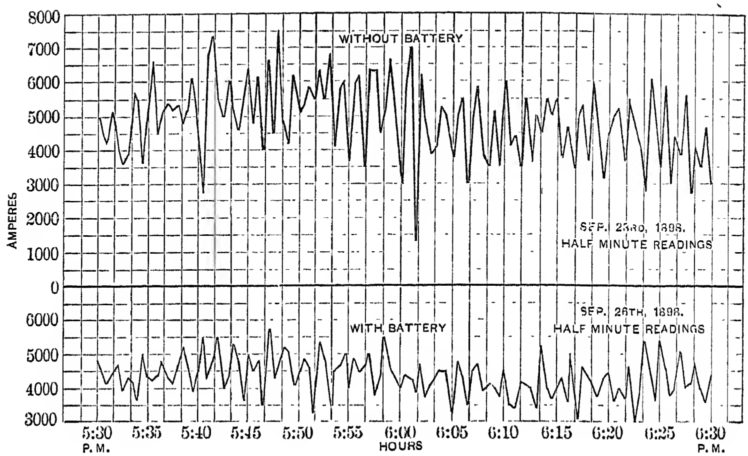


Fig. 8.—Curves showing Generator Load at the Power Station of the South Side Elevated Railway Co., Chicago, Ill.

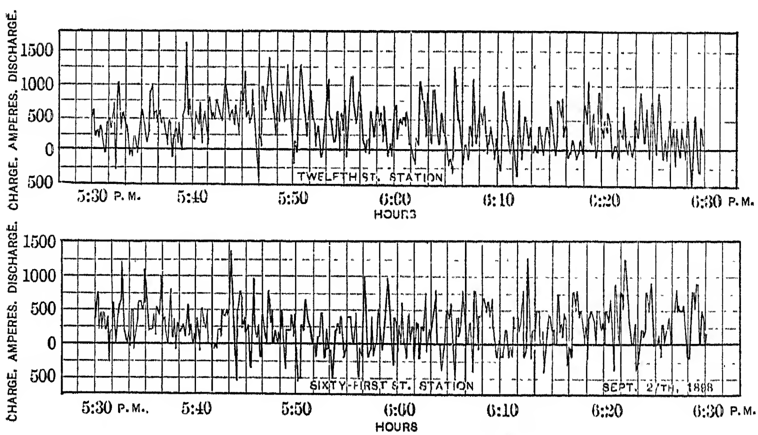


Fig. 9.—Curves showing Regulating Effects of Batteries at the 12th St. and 61st St. stations of the South Side Elevated Railway Co., Chicago, Sept. 20th, 1898.

Discussion in New York.

The President:—The paper to which we have just listened is now before the Institute for discussion. The discussion ought to be interesting—fully as interesting as the paper has been, because there is set forth in the paper a proposition which seems at first sight a very radical one, and that is to have a battery in a power station costing more than twice as much as the steam plant. The question as to what proportion should exist between the generating system and the storage system in a central station, is a very important one from an engineering and a commercial point of view. The usual plan has been to regard the storage system as a relatively small and auxiliary part of the generating plant. In this paper, however, the proposed plan is to make the storage battery the principal element. The paper is now before the meeting for discussion.

Mr. George Hill:—Although I am not in the street railway field, I have done a little in the line of storage batteries, and my criticism of the paper would be that the point which you emphasize, Mr. President, as being worthy of discussion, has not been sufficiently emphasized by the author of the paper. I would go much further and be much stronger in my advocacy of a large storage battery than he has been under the conditions given. I have had an experience extending over nearly three years with a storage battery installation designed by myself for an office building here in New York, in which the storage battery cost I think, a little over four times as much as the generating plant. The installation was in a building 75 feet by 100 feet, six stories high. The ordinary fuel consumption in such a building would be from 300 to 450 tons per annum. The fuel consumption in this building is an average of 118 tons per annum. The installation, I think, was the first one of the kind in which no attempt was made to load the engine other than with the storage battery. In other words, it was the first attempt to give the engine a uniform load throughout its period of work. I figured carefully the requirements of the building, and installed two complete sets of cells, each one having an ampere-hour capacity sufficient to handle the entire building for at least fifteen hours. At the start we found that we had sufficient capacity to handle the building for two and a half ordinary days. Later on, as the building filled up, we found that we had, and we now have, capacity to handle the building one and one-half ordinary days, or easily through the heaviest day that we have ever had.

The entire apparatus is of the simplest possible description. The switchboard simply contains the recording instruments with duplicate generator and battery switches; simply two double-throw two-pole switches, so arranged that when the handles are on the same side, one set of cells is discharging, and the other set of cells is being charged. In the morning, when the engineer

starts up his plant, he simply transfers the two switches so that the handles are both on the opposite side, and the cell that was charged the preceding day is discharged, and the exhausted cells are again charged.

At the time, the storage battery company from which I purchased the plant did not understand why we were squandering so much money for storage batteries. In order to relieve their anxiety I went over the relative cost of the engine, generator, booster, various regulating rheostats and automatic devices, and we found that the additional cost would not exceed a thousand dollars, or about the annual cost of the additional fuel due to the fact that there the generator would not run at a constantly economical load. The operating economy of that plant is phenomenal, as 118 tons of coal furnish all the light, heat, elevator service, pumping, fan service and every other requirement of light, heat or power in the building. Commercially considered, we

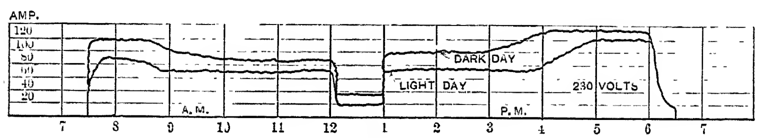


Fig. 2

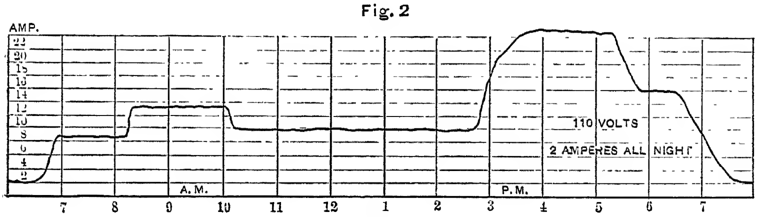


Fig. 1

expended about $4,000 more than the usual plant would have cost, and saved the interest on $11,000—a net saving of about $420.00 per annum. The load curve is like Fig 1. For pumps, lights, etc., the elevator duty would show as a fringe of vertical lines of 60 amperes, one for each minute from 8:45 A. M. to 5:45 P. M.

On the other hand with a load curve like Fig. 2, which is taken from a manufacturing building designed by me operated with a direct connected 50 K. W. generator, the load comes from four electric elevators of good speed and large capacity; 75 horse-power of motors and 300 lamps. The load ranges at about 17 K. W. with frequent fluctuations up to about 66 K. W., and a few drops to 11 K. W. The total monthly output is 9,000 K. W. hours; the coal consumption for the generator, pumps and for live steam to various heating appliances in the building, paste making, etc., is about 170 lbs. per hour in

the summer, and about 200 lbs. per hour during the severe weather in the winter. The curve shown is the light and motor curve, the elevators would add to it a fringe of vertical lines, two per minute from 7:30 A. M. to 6:15 P. M. 75 per cent. adding 45 amperes and 25 per cent. adding 90 amperes. If we then figure the annual coal consumption for the building on the basis of 3,000 hours per annum we will have

2,500 hours	at	170 lbs.	equal	425,000 lbs.	
500 "	"	200 "	"	100,000 "	
			"	234 tons	equal $610.00.

If we try to perform the service with storage batteries and install them under the most favorable circumstances we will have 33 K. W. per hour. Assume that our engine can be installed so as to take no more than $1\frac{1}{2}$ lbs. of coal per brake horse power, that our generator has an efficiency of 90 per cent. and our storage batteries an efficiency of 85 per cent. This means an hourly coal consumption of 84 lbs., then fuel would figure

2,000 hours	at	84 lbs.	equals	168,000 lbs.	
500 "	"	170 "	"	85,000 "	
500 "	"	200 "	"	100,000 "	
			"	$157\frac{1}{2}$ tons	equals $410.00.

The saving of $200 capitalized at six per cent. would be $3,333 or manifestly insufficient to pay for the additional cost of the more economical engine with its condensers, etc., leaving nothing for the storage batteries.

Every plant must be considered on its merits, and the use of one or two systems decided on according to the requirements of the case. One system being the direct generation of current in which the engine should be proportioned to work at rated capacity with $\frac{3}{16}$ cut-off being of a simple high-speed type, and operating normally under a pressure of 90 lbs. but with the parts so proportioned as to transmit easily a 30 per cent. overload, the speed being maintained by a much later cut-off and increase in pressure. The generators should be of the heavy design generally met with in present practice with wide non-sparking range, carbon brushes and with very low current density in the parts. The K. W. capacity should be so determined that the momentary peaks shall produce overloads up to 40 per cent. The other alternative would be the generation of current in a compound, condensing, direct connected plant with high steam pressures. All of the current stored in duplicate sets of cells each one equal to one day's discharge, and the plant operated with one set of cells being charged while the other was discharged. The engine running from 12 to 24 hour shifts and loaded continuously to its most economical point. It is my belief that where storage batteries can not be shown to be economical under these circumstances they have no place at all in new installations. It is of course necessary in any plant to insist that it be operated in the manner in which it was designed to operate. There are no

doubt many cases in existing plants where storage batteries can be advantageously used, but they are special cases for which no general rule can be laid down.

The point mentioned in the beginning of the paper in regard to excessive kilowatt capacity installed, as compared with the actual output leads me to imagine that the central station engineers are meeting some of the difficulties that I experienced eight years ago when first calling for engines to supply light and power to buildings. That is, all parts too light.

It may be interesting to state, in connection with the item of depreciation, that my experience with the storage battery plant before mentioned, shows that if the plant is in charge of a competent engineer, depreciation can be neglected. In the three years that this storage battery has been in operation we have expended certainly not five dollars, the chief engineer tells me nothing—for renewals or repairs, and I believe that the cells are in better shape to-day than when they were first put in, and from their nature should not depreciate. It is necessary, however, in order to give the engineer a chance, to so design the plate connections and from them to the 'bus bars of the switchboards, that each plate shall have practically the same amount of resistance. The details furnished to us to make this installation I found thoroughly unsatisfactory and so changed them materially, and to this I attribute much of the successful operation of the plant. Of course the engineer understood his business thoroughly and carefully watched every plate so that there was no chance for them to run down. It would be unreasonable to expect that all engineers would be as careful, and we must make some allowance for depreciation due to this cause. It may also be desirable to make some allowance for depreciation due to improved methods of manufacture, but generally, I think it fair to say that the depreciation of a properly designed and properly handled battery plant should be insignificant.

Mr. C. O. Mailloux:—This paper is a complete statement of all the salient features and advantages of the storage battery as a factor of economy in central station practice, and it gives all the principal points which the engineer should take into consideration in designing a plant wherein he intends to utilize storage batteries. I agree very fully with all the statements made by our colleague Mr. Lloyd, and I particularly appreciate the stress which he lays upon the preponderance of the storage battery. I use the word preponderance because the importance which he ascribes to the proportion of the storage battery seems like a preponderance to those engineers who are not familiar with the advantages of the storage battery, and who are still skeptical or conservative in its use. I have had occasion to utilize batteries myself, and the practical results have indicated very clearly that the principles enunciated by Mr. Lloyd are correct, and that they can be demonstrated by actual practical results. The diffi-

culty has been to make people realize the possibility of this. As you know, the time was, and it has not been far back, when the word storage battery was a very dangerous one to use by any one who wished to retain the respect of his colleagues in the electrical engineering fraternity. I am one of the unfortunates who have had to suffer the result of my misguided, early, pioneer, zeal in that direction. The rapid growth of the storage battery in the last three years is a circumstance of great satisfaction to such as myself, who had to bear the jeers and taunts of derision in years past.

There is one point which the last speaker referred to, namely, the point of depreciation, which I think ought to be carefully considered. My own experience with storage batteries covers a period of at least ten years, during which time I have seen batteries come and go—mostly go; and, in spite of the fact that I have great faith in storage batteries, having always been an apostle of their use—I cannot quite concede the propriety of the statement that no allowance, or at least only very small allowance, need be made for the depreciation of storage batteries. A battery may, indeed, work quite well for the first year, the first two years, the first three years; I have seen them work five years, under conditions where they require little or no allowance for depreciation. But I think it is an error to believe that because it is postponed five years, the day of reckoning is not going to come, because it certainly will come; and I think that the careful engineer should not mislead—his zeal must not mislead him to the extent that he must not make a fair and due provision for that day of reckoning. Good engineering practice dictates that one should make an allowance for a certain item or percentage of depreciation of the storage battery just as one would on other things, I have myself found that it inspires confidence in a man who has been hitherto a skeptic on this subject, to tell him frankly that he must allow 10 per cent. for depreciation of the storage battery, because when he finds, later on, that it is only costing him six or seven per cent. to maintain his battery during a period of ten years, he has more respect for both the engineer and the storage battery; whereas, if he had been told that it would take little or nothing, and he afterwards discovered that it did take as much to maintain it as the rest of the plant, he would not have felt so well about it.

A singular instance of this has occurred in my own practice. I installed a plant in connection with a storage battery some four or five years ago in an office building. I think it was the first office building in New York city in which storage batteries were introduced. The principal reason, and perhaps the only excuse at that time for their introduction was the necessity of making provision for lighting at night, as the offices were occupied by tenants who at times did night work, and must have electric light. It was sought to make arrangements with the street light-

ing companies for a so-called "breakdown" connection or supplementary supply to be used at night; but the terms exacted were not deemed satisfactory to the owner, and he finally seems to have lost his temper and to have decided that he would allow such a reckless thing to be done as to put in a storage battery, although he evidently looked upon it more in the light of a necessary evil, or something that one could do, perhaps, to spite someone else, rather than because he was actuated by motives of economy or good engineering. I remember frankly stating to him that the storage battery was not to be regarded as a luxury, even though I believed it to be practicable in this case; but that its use involved certain losses and expenses and that he must face the possibilities, some of which might not be reassuring. I did this for several reasons: First, because I was none too sure myself as to the future and the possibilities of storage battery maintenance, and secondly, because I wished to disappoint him agreeably if at all. The figures of estimated annual costs which I presented to him seemed rather large although they still were less than what he had been paying for current. He finally decided to adopt the storage battery. He had misgivings as to whether the percentages guaranteed could be maintained, etc. After the plant had been in operation about two years, I went to this gentleman to get figures in regard to the economic results. The gentleman hesitated greatly, and finally said that he did not care to give me any statement. He would simply state for my information that not only had I met all the promises which I made to him, but that the results had been so much more satisfactory that he had respect for my modesty and did not wish to strain it by making me feel too good. This case illustrates the importance of not deceiving the client, or rather of misleading him by being too zealous or having too much faith in yourself. I feel quite certain that if I had understated what he might be expected to pay for the depreciation of the storage battery he would not have given me such a complimentary report, and probably would have been very glad to show me the figures after two years, and to have "rubbed them into me," so to speak.

It is, perhaps, to be regretted that the author did not elaborate a little more fully those explanations and calculations on which the conclusions are based. There is no doubt that the facts as stated are correct, and that the principles on which they are based are also correct. Nevertheless, to those not thoroughly familiar with the subject, and especially to those who are at all inclined to be skeptical, a little more detailed information regarding the reasoning on which the results are based would have been of interest, for example, some figures showing a little more fully than is shown in the tables, of cost, the manner in which the advantages vary with the size of the battery, or the proportion between battery and electric generator plant.

The plan mentioned by the last speaker, of utilizing the cur-

rent entirely from the battery, may have its advantages in some cases; though its utility, especially in large installations, would seem to be more doubtful. In large installations it is necessary to run machinery for generating energy for such a large proportion of the 24 hours, that the equipment might just as well be arranged in such a manner that a great percentage of the energy would be utilized or fed into the feeders direct, instead of into or through the battery. In this way the economy of the plant is increased, and one is enabled to secure better conditions of economy with a smaller total initial cost. As for the annual cost of operation, I think there can be no doubt that it would be very much smaller with proportions such as are advocated by Mr. Lloyd.

There may be, of course, advantages incidental to one plant or to another which dictate its adoption, because they may become considerations of peremptory and paramount importance in special cases. But in the absence of such arbitrary considerations, it seems to me that those conditions which produce both the highest load factor and the best economy in the generating plant, are generally apt to be those conditions which lend themselves to the least total yearly cost for the total energy output per annum.

Mr. E. T. Birdsall:—For the past few years I have been following this practice as closely as I know how in railroad plants that I have built. I have used the battery both as a pressure equalizer and also as a load equalizer in the station, and with very good results, and I think it has only needed a battery that we could rely on for everybody to fall in line in this same practice. Its benefits and advantages are self-evident, especially in lighting plants. All we have to do is to look at the gas companies and see how they operate. They do not need any two-rate meters or any maximum demand meters or anything like that to charge for gas, and they appear to make money. They make their gas right along, 24 hours a day, and put it into a reservoir. Of course, storage batteries cost more than gasholders, although not so very much more, and I think lighting companies will gradually come to the point where they will pump the electricity into a big battery and let the customer use it as he pleases. Of course I realize that a customer who uses his current at the same time that everybody else does, makes the station buy a little more battery, but it is not as bad as boilers and engines, and it is better for the economy of the station.

In regard to Mr. Lloyd's first paragraph, I think that is the truest thing I have heard in a long time. I have recently been through all the railway plants in a large city, some seven of them, and I think the reason that most railroad plants have more capacity than they need, and run more engines and dynamos every hour than the load requires, is because the engineers like to have an easy time. As a rule you will find the engineer in a large

power-house has a nice room which is comfortable and warm and free from dust, or a fine raised platform with a shining brass railing around it, and he likes to sit there and read the technical journals and have a chat with his friends. If he had to go out every few minutes and close circuit breakers that would not be comfortable, and he does not propose to do it. It is so much easier to tell the man to start up another engine and dynamo. Although this may seem like a joke, I really think that it is the main reason. As I say, I have recently been through the stations and in every one of them—it was very snowy and cold outside the day that I went around—the chief engineer was having a very nice time in the station, and there were plenty of engines running inside the station, and very few cars outside. No circuit breakers opening and very few scars on the breakers. The great thing that most of these railroad companies need is a general engineer to go around and shut off engines. All these plants had plain Corliss non-condensing engines, and a number of them belted generators; about half of them were in wooden buildings and almost all the machinery was painted very elaborately. The amount of paint was something marvelous, and this was in a good sized city, about the fourth city in this country, and the coal—well, there was lots of coal—but all the companies were making money, and if the company makes money, why change? That is the great factor in boards of directors. I have encountered that several times myself. They say, this plant is earning 10 per cent; what better do we want? Why should we spend a lot of money and have more bonds and everything like that when this thing is good enough—what's the use? And those are the things that engineers have to contend with. It is against "good enough" and the engineer in the station who is having an easy time.

MR. MAILLOUX :—There is another point which has been noted by Mr. Lloyd and which might be enlarged upon. It is the difference in economy of engines under varying loads. A very able paper on the "Performance of Street Railway Power Plants" was presented at Chicago in 1893, before the International Engineering Congress, by Messrs. W. A. Pike and T. W. Hugo, which contained some interesting data on this point. The authors called attention in their paper to the results of experiments with a certain engine, which plumes itself upon its ability to maintain a nearly constant efficiency line under wide variations of load. These experiments showed a difference of 30 per cent. between running on the fluctuating loads of the trolley line feeders, and running on a steady load obtained with artificial resistance, such as a water rheostat. In other words, the efficiency of the engine when measured by taking a large number of indicator cards while the engine was operating under fluctuating conditions, and taking the same engine running at the same mean load on a steady resistance showed a difference of about 30 per cent. [The exact steam consumption given by the authors was 29.2 lbs. for trolley

load, and 22.5 lbs. for steady load.] Now, if this is the result which is to be expected from an engine which is especially built to respond to such wide variations of load while retaining an approximately constant efficiency, one can surmise what will be the difference in efficiency when the engine is not specially built for such variations.

In connection with the matter of fluctuations, since we shall probably see more use made of storage batteries in future in large central station practice, I think it is well to begin to establish a notation. In a paper which I read on this same subject before the *American Street Railway Association* at Milwaukee in October, 1893, I endeavored to make a start in that direction by seeking to establish a distinction in the various kinds of fluctuations with which the storage battery has to deal as an equalizing factor. In other words, there are those variations which take place from hour to hour, a part of which occur in the peak of the load. To these I have thought that the name "variation" was more appropriate; whereas, those momentary and instantaneous fluctuations which take place from one instant to another might better be described and defined by the term "fluctuation." That is, the term fluctuation might better be restricted to those short and quick fluctuations, while the term variations could be retained for the longer ones which determine differences in the mean value of the load from hour to hour. To quote from the Milwaukee paper:

"I would use the term 'variation' to designate the effect caused on the station plant by putting on or taking off a certain number of cars; and the term 'fluctuation' to designate those incessant and erratic ebbs and flows of current which are so familiar to us all, due to the starting and stopping of cars, changes of speed, grades, etc. The variations of load are defined as changes,in mean or average rate of production for a given period of time; the fluctuations of load are defined as changes in rate of production from one instant to another. . . . . . .

. . . . The term fluctuation should, in my opinion, include both the 'waves' and the 'sub-waves,' while the term variation should be restricted to the 'billows.'"

Again, in dealing with a battery, we have to consider some of its features and peculiarities. We have to consider a battery from the standpoint of its total storage capacity, such as for instance, whether the battery is medium, large or small, as Mr. Lloyd puts it. It seems to me that a term would be necessary here, especially when we attempt, as we shall soon, to formulate the conditions and the principle under or by which a given size of battery is to be determined. All attempts at this formulation have failed hitherto, because there are still several unknown quantities in a storage battery—notably, the depreciation, or to put it more accurately, the rates of depreciation under varying conditions of service. We shall doubtless have abundant material on this subject in the course of a few years more, seeing the

rate at which storage battery installations are now being put up; and it will then be possible to formulate methods by means of which the best equipment can be determined just as perfectly and with as much ease as we now predetermine the details of a dynamo or a motor. Now, in doing this we shall have to consider, as I said before, certain peculiarities of the battery; one is its total storage capacity, to which I have given the term "quantity factor," and another is its rate capacity; that is to say, the ability of the battery to "give and take" energy, or the maximum rate which it can be called upon to deliver or absorb, for the purposes of load equalization in taking care of those changes which I term "fluctuations." I call this the "rate factor." Now we connect the rate factor with the fluctuation because it is the feature which is of utility in connection with the fluctuation, or the ripples in the load curve, and we connect the quantity factor with the variation, because it is that which is useful in the leveling out of the larger excrescences, or the "billows" in the load curve. As a matter of fact, the size and the cost of the storage battery, in a given case, depend mainly if not wholly, upon these two factors. Sometimes one of these factors, sometimes the other alone, and sometimes both together, will influence the size of the battery needed for a given case.

Extract from the Milwaukee paper:

"Your committee has found it convenient to designate these as the 'battery factors,' calling the first the battery 'quantity factor,' and the second the battery 'rate factor,' in which case they are expressed as ratios. Thus the quantity factor is defined as the ratio of the quantity of energy to be drawn from the battery, to the total quantity to be furnished to the (trolley) circuits under maximum conditions, while the rate factor is defined as the ratio of the current to be furnished by the battery to the total current, also under maximum conditions.

F. V. Henshaw:—I would like to ask Mr. Lloyd whether in the figures for cost of storage battery given on page 51, anything is allowed for boosting apparatus or any dynamo-electric machinery for raising voltage in order to charge, or any allowance for switches for cutting in and out cells for regulating voltage in that way, or whether it simply includes the storage cells with their connections.

Mr. Lloyd:—I might as well answer that now. I allowed the sum required for the entire storage battery installation and apparatus, and I just want to show you how simple that table is. The calculations are not as complicated as Mr. Mailloux might have given you to understand. The first three columns I got from the office of the storage battery company, which, of course, are available for everybody. As to the cost of coal per day; for number one plant with no battery, I took exactly what they were burning at this place—which was 15 tons at $2. For the large plant I took the standard of the Chestnut Hill

pumping station in Boston, which would have been $7\frac{1}{2}$ tons, allowing for the loss in the storage battery, which you see only amounted to half a ton per day. So that even with a large storage battery, the loss due to the use of storage battery did not make very much of an addition to the total coal consumption. That was $15. The two figures in between, 25 and 20, I did have to guess at, to some extent, and yet I think that they are fair figures. The cost of coal per annum, next column, is figured from the last, and the saving in coal is also figured from the last, taking the very near station as the standard. I did not put the interest in a separate column, but of course you notice the difference in the investment in each case, and I simply added together the saving in interest over the No. 1 plant, and the saving in the cost of coal. I put down the same amount for investment in real estate and building, and allowed the same for repairs and depreciation, and I credited the large plant with a saving of one man on each shift in this particular station. There might be stations where that would not occur. In this particular one it would, because they had two firemen, whereas, with the smaller boilers running they could get along with one night and day. The saving in water, oil and waste I took from the engineer of the station himself, and the total saving is simply an addition of the others. The estimated addition to receipts I got from the manager of the road. He said if he could raise his circuit breakers as much as would be allowable with that medium size battery, he thought he could take in a thousand dollars a year more without any trouble, and if he had an additional flexibility due to the large battery he would take in five thousand dollars. Of course, the last column is the addition of the two former ones.

In regard to the cost of coal per day, of course I might have gone very deeply into that subject. But I ought to say that this station was a particularly economical one, as you will see if you will look up that curve and take $30 a day for coal, it is a very low cost. There are very few stations that could do that. The engines are compound condensing of the Corliss type and of high standard as to manufacture. The whole station was quite as good as you will find anywhere. At the present time these things are being put in perhaps a little bit better. But it was certainly good for the last few years. The economy was certainly fine on that day. The fact is, I do not suppose the average of the railway stations of the United States would come anywhere near that small coal consumption. Their coal consumption would probably be at least twice, and perhaps three times as great.

I have answered the first question. As to the estimated costs in column two. Those costs include everything except real estate.

While I am on my feet I want to say, in regard to the first speaker's criticism, that this is an extreme view of battery prac-

tice, I do not say that is the best one; it is one that occurs to me, and I know that a good many people do not agree with me, and it may not apply to all cases. It does apply in the station which I have especially studied. There is not any question there but that a large battery giving the opportunity for a more profitable use of current outside of the station, and more economical production of it inside the station, has advantages over either of the smaller installations of battery. It might not be so in the case of New York, although I think it is likely to be more so, because current between 5 and 8 o'clock in the afternoon in New York is wanted more than it is in the ordinary country town, and between 1 at night and 5 in the morning it is worth almost nothing. You can buy it for three cents a K. W. hour, and if the great producers of electricity simply look at the lighting curve and remember that that big load or peak is going to go on top of that railway peak at one time, they would see at a glance that they might as well generate that current in the small hours of the morning, and sell it at 15 cents per K. W. in the afternoon, rather than hunt for some consumer who will pay three cents for it in the early morning hours. So I think there is at least a prospect that my position may be right, but I hoped it would draw out discussion, and as I told Dr. Kennelly at the beginning, I hope you will not hesitate to punch holes all through the paper, but you have treated it very kindly so far.

MR. JESSE M. SMITH:—I had occasion a few years ago to make a test[1] of a small suburban electric road; 150 horse power engine, 150 horse-power generator, and I took readings every five seconds for 10 hours on the ammeter and voltmeter, and indicator cards every five minutes for the same length of time. The average load on that road throughout the day was less than one-third of the capacity of the generator. The average load on the engine was less than one-half of the rated capacity of the engine. There would be an excellent opportunity for a storage battery to equalize the load. The maximum load in that case never went above the rated capacity of either the engine or the generator. The average load on the engine was 70 indicated horse power. The average load on the generator was 45 electrical horse-power. I might say there were only three cars on the line, and the maximum load would come on and go off in less than five seconds. The load would vary from 81 I. H. P. to a maximum of 141 I. H. P. in less than five seconds, and that happened probably a hundred times in the day.

MR. F. S. HOLMES:—We should not lose sight of the fact that the extreme variations, which have been called "fluctuations," are characteristic of small stations rather than of large, and that the larger the station the steadier the load. I have seen the same conditions prevail in a power station of about the size spoken of

1. See Proceeding *Am. Soc. Mech. Engs.* Vol. XV. Page 730.

by the last speaker, where perhaps five or six cars were taking current. Now if you make that 25 cars, the load, by the law of general average, will be less subject to variations.

Some time ago I was called in to advise a certain concern on electrical matters. The people knew a great deal less about mechanics than they did about some other matters. They were extremely shy of electricity, because they had had very disastrous experience with some electric apparatus. That apparatus happened to be a storage battery which was less than two years old, and was perfectly dry. I was not surprised, because upon visiting the engine room I found evidences of a primitive style of electrical operation—switchboards that were very much out of date, and electrical apparatus that was very poorly hooked up. If one is going to get the conditions that have been suggested by the first speaker, where there shall be nothing allowed for depreciation, then a very considerable amount must be allowed for the brains of the mechanic who takes care of the plant.

Before sitting down, however, I ought to say that I am very much in sympathy with the general statements of this paper. I agree with the speaker entirely in his statements in regard to the economies of an engine under a full and constant load. I suspect that that engine, that "plumed itself," according to the second speaker, on its ability to maintain an economical rate between wide ranges, was a compound engine. Cylinder condensation and clearances in engines of that character would not make them the most economical engines to run under conditions of sudden and wide variations.

MR. MAILLOUX:—I would like to disabuse the gentleman of the impression that because the plant is increased the fluctuations necessarily disappear. If he will look over the load curves which have been published in large numbers during the last year, and also the curves published in a paper on "Electric Railway Motor Tests" read before the INSTITUTE in 1892, he will find that fluctuations occur in a space of a few seconds, sometimes a few minutes, which may represent as much as 20 or 30 per cent. of the generator capacity of the plant, even with a plant of over two thousand horse-power capacity. Hence while the fluctuations may not be instantaneous in the sense that they are with a little three-car plant, yet since they take place within a period of time so short they must be considered as fluctuations, because they are just as important in their effect on the plant economy, and produce just as much discomfort to the station attendants, if not danger to the generating machinery as the fluctuations, as in the case of a three-car plant. It may be said that while the little kinks, or the ripples in the curve of fluctuation are smoothed out to some extent in the manner stated, yet it is by no means true that they disappear altogether, or at least to such an extent that provision should not be made to equalize them. The particular case that I referred to was the electric station at Minneapolis, to which I made a

somewhat detailed reference in my own paper. It will usually be found that the economies obtained even with stations of that kind are quite disastrous when compared with the theoretically attainable economies.

MR. H. B. COHO :—I had an experience with the storage battery some years ago, about the time of which Mr. Mailloux speaks, and find it difficult to grow enthusiastic on the subject of repairs. I remember, in 1892, operating a storage battery car. We had one car in service, and after two months intermittent service without renewing cells I wrote to the president of the company stating that at last we had attained perfection and would make our fortunes. Two days after I had sent this enthusiastic letter, my motorman came to me and stated that there was something wrong. I casually remarked that trouble was due to the motor and dismissed the subject. The next day we could do nothing whatever with the battery, it having gone to pieces entirely.

From the above experience I am strongly in favor of giving the matter of depreciation very careful consideration. I do not feel that the 10 per cent. depreciation which Mr. Lloyd figures on for machinery is as fair to the machines as it is to the battery. I agree that it is only fair to tell the prospective purchaser of a battery that his renewals may equal 10 per cent. per year, while I do not feel that it is fair to say he must charge off 10 per cent. per year against his electrical machinery, as to all practical purposes his steam plant may be just as operative ten years after starting as it is in the beginning, and nothing like 100 per cent. of the cost has to be expended in renewals. On the other hand, we must admit that batteries must be renewed and new batteries put in from time to time.

This whole matter really boils itself down to one of dollars and cents, and while I think we all agree as to the advantage of the battery in a great number of instances, yet I would certainly recommend the station managers and others contemplating the use of batteries, to consult with skilled engineers before going ahead too rapidly.

I agree with Mr. Hill that there are advantages to be gained in making the working parts of his engine large in proportion to his cylinders, and that he gets a more easily operated plant as regards attention by doing so. For a building the size he mentions, a storage battery is undoubtedly a good thing, although I take issue with him on the subject of renewals. He wants to look out not to find himself in the position of the Deacon with his "one horse shay."

In conclusion I would say again that I believe the installing of a storage battery in connection with generating plants is altogether one of dollars and cents, and that due consideration must be given to the subject of repairs, and that it is hardly fair to say that a steam generating plant deteriorates 10 per cent. per annum in regular use. Improvements of course have their

effect in cutting down the value of machinery, but second-hand machinery always has a value, while the value of a second-hand storage battery is still a problem.

MR. MAILLOUX:—If no one else wishes to speak, there is another point that I would like to dwell upon. It is related to this question of depreciation. I have made several contracts for depreciation. I consider that the concern furnishing the battery, if the circumstance allow it, is the proper party to look after the maintenance of the battery, and that, other things being equal, it can do it more satisfactorily and more cheaply than the purchaser. I have generally, in preliminary estimates, taken 10 per cent. depreciation on the cost of the battery, but I must state that the contracts I have made have never exceeded 8 per cent., and I believe that in actual practice, the battery when not subjected to abuse, can be maintained for probably 7 per cent. In lighting stations the maintenance is even less, which, by the way, is due primarily to the fact that the battery has a relatively larger quantity factor; but where the battery is subject to fluctuations, using the term in the sense which I define, it generally depreciates somewhat faster and a greater allowance should be made for depreciation. I have seen cases where ten per cent. would not be too much allowance for depreciation.

In a thorough study which I made of the matter while in Europe, some three years ago, I found that the percentage of depreciation in continental installations of a size such as are installed, for instance, in Germany, at Hanover, Dusseldorf and Berlin, in the central stations, and in other places, the percentage of depreciation does not exceed five per cent. per annum. In most cases the central station company itself maintains the battery, and the total cost, including all expenses, does not exceed four per cent. A point of importance which I wish to allude to is that the size of the battery which one can afford and which one ought to put into a central station depends upon the percentage of depreciation. The lower the cost of depreciation, the more battery one can afford to put into a central station, the more one should put in, in order to obtain the maximum economy. This point is based upon mathematical relations which become perfectly apparent even on elementary study.

MR. JOSEPH BIJUR:—There are two questions that I should like to ask Mr. Lloyd. The first is, does he consider that the battery is as much an essential part of any station, railway or lighting station, as the engine, boiler and dynamo? In other words, is an engineer designing a plant to immediately assume that the battery will be used in any case, irrespective of the load? Does he think that the battery has developed to a point where its use will be always advantageous, or, are there cases where a battery may not be advisable?

The other point on which I would request some information is the reason for the very large difference of opinion that still

exists, I think, as to the use of batteries in large stations. I have seen both here and abroad a great difference of opinion in that respect. I recall particularly, that in Berlin, in 1893, they were operating about four different stations with large units, and the management did not believe in a battery at all. They thought that the best method of operation was to shut down or start up generators, as the case might be, corresponding to the requirements of the load. As three or four of their stations were tied together, when the load for any single station became too light, they simply shut that station down, transferring its load to another station. This was a lighting plant, so that at times of light load one station was carrying the whole city. I have seen the same thing done in railroad practice where two stations were tied together. On the other hand, in a city not very far away, they thought it quite essential to use a battery and the battery was used, I think, in the proportion that Mr. Lloyd suggests, that is some 70 per cent. battery to 30 per cent. machinery, and there was no apparent reason why these two companies should hold such different opinions. They could buy the same make of battery, and yet this distinction existed, and I think we find the same difference of opinion in this country.

Mr. Lloyd:—I want to explain a little more clearly what I meant by depreciation in this paper. I see it is not very plain. Both in machinery and other apparatus, it is hardly likely that any will be in use, as I said, much more than twenty years, a great deal not more than ten years. If it is not worn out it will be out of date and the man will throw it away and get something else. In the case of steam engines, it is very likely that the use of superheated steam, especially with constant loads, will revolutionize steam practice. I do not say that it will, but it is one of the possibilities; and we always have to look forward to the direct production of electrical energy from coal without any steam engine, and I do not think that I should want to own a plant in which some allowance was not being made for the eventual throwing away of the whole apparatus in the course of ten or fifteen years, and while the actual repairs to the machinery might not be more than two per cent. per annum to keep it in good working order, it is very likely that the apparatus itself would be thrown out or the roads would be consolidated, or something else happen that would render that machinery useless in the course of a dozen years. In regard to the battery, the depreciation might be nothing for five years, and then a new set of positive plates, or a new set of negative plates goes into it, so that while the actual repairs and care of the battery, amount to very little, there must still be an allowance for renewal of plates. A battery has the slight advantage that in adding plates from year to year, or at intervals of three or four years, you add the best ones that are made at that time. You are not simply repairing an old machine, but you are putting in new machines that are up to date,

and I think likely that the man has a better battery than he had before. I know a number of the plants that have been spoken of to-night where renewals have been made, better stuff has been put in the battery, and the batteries are better now, and after ten years a battery will be a little more up-to-date than it was when it started, though even then it may be thrown away on account, as I said, of possible consolidations or for a thousand other reasons. I take 10 per cent. as being conservative also, because a good many railway engineers have told me that they are positive that their flywheels and their bed-plates, and other parts of their engines are crystalizing in such a way as to make them dangerous in the course of time. Even if they keep up bearings and other things, certain other parts of the machinery are liable to changes in the constitution of the metal, and they will be afraid to run them when twenty years old. In the particular station that I have referred to here, the real reason for the excess of maximum capacity is very plain, and probably applies to a great many others; that is, that the engines cannot be run at a maximum load or anything like it, even allowing for setting the circuit breakers a good deal beyond the maximum load. If these engines are running at full speed and with full consumption of steam, and the circuit breaker goes out, the engine runs away a revolution or two, and the result has been in this particular station since one of the pedestals broke down, and came very near wrecking the station, that you cannot get the engineers in attendance to run the engines in that way, and I have no doubt that this is true of other stations. There are other reasons, of course—economy and all that sort of thing. But it is simply impossible to run a station when the engineers are afraid of flywhesls or anything else giving out, so they always have a great deal of reserve capacity.

In regard to the two points of the last speaker, I said in my paper that it was not safe to assume that the battery was always necessary. I think every case ought to be treated as a special problem. I know that there must be cases where a battery ought not to be assumed essential. In some localities water power is so cheap that it is not worth while storing energy, and there might be other conditions. We have attacked a good many problems in Pittsburg and took particular interest in them because coal was delivered at about 45 cents a ton, (slack coal), in the power-house of the Consolidated Traction Company there, and yet they found it best to add storage batteries to their installation, largely on account of the depreciation problem. They have put in magnificent machinery there, and they would not try to run it without a more steady load than the ordinary railway service would provide.

As to the difference in the views of engineers regarding the quantity of battery, and as to running big engines, I think time and experience will tend to establish a more uniform practice.

People have not yet discussed the subject sufficiently and there has not been enough data published, or enough effort made to obtain data. I am very sorry that my own paper is so incomplete in that respect. I hope some day that we shall be able to present a really thorough research in this class of work.

I referred in this paper to a way of using batteries that I thought perhaps some one might speak of; that is a possibility of simply using each generator with a constant load as it was added on, so that the day's load in a lighting station would be a series of steps, but each generator that was put in service would, by means of a battery of medium capacity, have a steady load. But I think that it would be very difficult for an engineer of a station to follow these steps and put generators on just when they are needed; and for that reason I have not allowed the same economy in running engines that way as in a station where the engineer is perfectly sure of what his load factors will be every day.

Mr. President, have I answered all the questions?

The President:—I think so, Mr. Lloyd.

Mr. Birdsall:—In these days when we are struggling to get the last cent out of everything and the last watt out of every pound of coal, it is quite discouraging to run across a peculiar plant, and I did it about a month ago. I was called upon to make a test of a plant to see if it could not be improved, as they thought that there was room for improvement. The plant was in a town of, I think, about 110,000 people. It consisted of two sheds; one contained the boilers and the other the engines and the dynamos. It was alongside of the railroad, so that they dumped the coal right from the cars into the boiler room. They had, I think, three or four horizontal tubular boilers and one Heine. Nothing of the boilers was covered, except by the brick-work at the side. The steam pipe was also bare. They had one cross-compound high-speed engine, non-condensing; two smaller high-speed engines, two Westinghouse standard engines, all belted to dynamos of various vintages. Everything that was a back number and everything that was queer they had there. They had a wooden switchboard with the finest collection on it that I ever saw. They had one of everything. They evidently had called for samples and put them up. The man who owned two-thirds of the station after taking me around it said "What do you think of it?" Well, I did not dare to tell him; I would have lost my job, as they say, right there and then if I had. I made notes of the machinery and then went back to the office. He said "I don't think that it is earning as much money as it should." Well, that was my opinion too; that is what I thought then. We went back to the office and went over the earnings. In the station everything was dirty. The boiler room was not fit to pile coal in. It was simply the worst I ever saw; and we went back and went over

the books. The man that I was with was the president and owned two-thirds of it. Another man was secretary and treasurer; he owned the other third, except one or two shares which somebody's wife owned, in order to make up the board of directors. That was the only station in the town. Upon going over the books we found that they had a capital of $25,000. They had machinery that must have cost them $40,000 at the time when they bought it, when the question was "How much has the man got?" not "What is the machinery worth?" They had capital stock of $25,000 and no bonds. They also had a surplus of $25,000 in the treasury. I saw that with great gratification. Then I saw that they had paid no dividends whatever since the plant started; but they had paid the president an average salary of $20,000 a year, and the secretary and treasurer an average salary of $10,000 a year. He said "Where do you see any chance for improvement?" I confess I did not see as much as I did when in the station.

As to the matter of the peak of the load I would say that I am running a road now in which we have about 40 cars and very few grades, and the load varies almost as much as it did when we only ran 10 cars on it. On holidays and Sundays when the traffic is bunched at a park on one end of the line, by that marvelous second sight that motormen have, to start every car at once, they open the circuit breakers very frequently. After the cars get started it appears to break the endless mental chain between the motormen.

[Adjourned.]

Discussion in Chicago.

A meeting of Western members was held at the Technical Club, Chicago, February 15th, 1899. The Local Honorary Secretary, Mr. R. H. Pierce presided, and the paper was read by Mr. B. J. Arnold.

The Chairman [Mr. R. H. Pierce]:—This paper, with all other papers on the same subject, necessarily makes a comparison between the first cost and the depreciation of electric storage batteries and steam plants. It also brings up the question of what is the cost of a steam plant per horse-power, and what ought to be the cost of producing a horse-power. This ought to open a wide field of discussion. I notice that Mr. Dow is present. From what he has told me about his own experience, he ought to be able to discuss this phase of the question. We have some figures of very cheap power here, which I think some one who is in that business ought to take up.

Mr. Alex Dow:—I am very much interested as a mechanical engineer, because the figures quoted of $2\frac{1}{10}$ lbs. of coal and 3 lbs. of coal per kilowatt hour, and so on, are figures of very high economy. They are only obtained in the largest power plants, and under favorable conditions. In lighting stations they are very exceptional.

The remark interpolated by Mr. Arnold with regard to the number of pounds of coal per kilowatt hour is strictly true, I regret to say. I have stations on my hands now that don't come down to nine pounds per kilowatt hour, and the best record in my own practice is five pounds for the 24 hours, and approximately four pounds on favorable occasions, with Ohio coal and series dynamos.

I have had occasion recently to consider the use of the battery which is classified as "small," to secure regulation at a distant point. The investigation took me into several lines of inquiry, and incidentally caused me to go over all the data that I had, and to make some experiments as to what could be done to control momentary fluctuations, and to take care of instantaneous variations of loads such as are shown in the curves here, while retaining a given steam economy; not to take care of them in the manner indicated in Fig. 1 by putting on an engine a great deal too large for the work, but to take care of them with an engine which would be economical under the actual conditions. I have found that the practice in a great majority of plants is to have an engine entirely too large for economy. I confirm most emphatically Mr. Lloyd's statement that in many stations the engine is too large even for the maximum demand; and that brought distinctly to my mind the idea that there is still much to be done in the way of adapting the steam engine to the actual conditions of electric lighting and power. Much can be done in the way of a proper proportioning of cylinders—usually in.

reducing piston area, while keeping the reciprocating parts of the engine strong enough for instantaneous maxima, and using valve gear that will allow a late cut-off. I find that it is possible with such an engine to take care of fluctuations away beyond the nominal capacity of the set, by merely having plenty of fly-wheel. I find that instantaneous loads of 10 or 15 per cent. above the generator capacity can be disregarded altogether; that the average of the load can be provided for by the proper selection of engine cylinders and cut-off in conjunction with a much heavier frame than is usual. The strong frame and reciprocating parts ensure that there will be no strains of an injurious character produced by those instantaneous loads in the engine itself. The generator of now-a-days does not break down under such conditions. Formerly, we used to strip armature windings when they got a sudden short-circuit or a sudden overload, but as the generators are now built, they don't do that. I should say the function of the "small" battery is not to take care of instantaneous variations which can be perfectly well taken care of by a steam engine; but is to take care of local variations which are complicated by copper losses in the line. I believe that the place for the "small" battery so-called, is on the outlying feeders where it can equalize drop in line and hold up the local pressure. I believe that the distribution of several such "small" batteries over a street railway system would be excellent engineering, and give good results when a similar amount of battery installed at the station would not be profitable or desirable. It would permit the doing of one thing the value of which is only occasionally appreciated; it would permit the use of copper adapted to the average load on the feeder rather than to the maximum.

The function of the "small" battery seems to me to be entirely to take care of local, single feeders. If anything should go in the station at all, it should be at least the "medium" battery, though the author advocates the so-called "large" battery. I think Mr. Lloyd is deserving the thanks of electrical engineers generally for those three expressions. They define very distinctly the work which is required of storage batteries under different conditions, and I hope they will be adopted by people generally who are carrying on that class of engineering.

THE CHAIRMAN:—I would like to ask Mr. Dow what, in the light of his recent experience in central station work, he thinks of the proposition of producing 557 watt hours from a pound of coal.

MR. DOW:—I think it is absurd. It is only possible to approximate it with a storage battery of the largest size.

MR. MAURICE COSTER:—I would like to ask a question of the gentleman who represents the storage battery interests. I note that the author in his paper places depreciation and repairs at 10 per cent. I would like to know approximately just what per-

centage of this is to be charged to depreciation, and what percentage to repairs.

THE CHAIRMAN :—Mr. Appleton, you may answer that in your own way.

MR. JOSEPH APPLETON :—About six per cent., Mr. Coster, is very fair for depreciation.

MR. COSTER :—According to that it would be four per cent. for repairs.

Mr. APPLETON :—Of course in a storage battery the depreciation is different from the depreciation of machinery. The way in which you provide for the depreciation of a storage battery is in time to renew the entire wearing parts of the battery. It is not the same in the depreciation of machinery. In taking care of the depreciation of a storage battery you renew entirely in time the parts which wear out, and therefore in a certain number of years you will have practically the battery in the same condition as when you began. Therefore the term depreciation of storage batteries bears a rather different meaning from the depreciation of machinery.

MR. COSTER :—In this connection I would like to express my opinion regarding depreciation of storage batteries, electrical machinery and engines. It is not safe for any engineer to estimate an amount less than ten per cent., per annum for depreciation. I was not surprised to hear that some engineers only allowed two per cent. I heard that a very prominent engineer recently made a similar estimate in the case of a large installation which cost over half a million dollars. I surprised one of the principal financial men in this enterprise by assuring him that this estimate was entirely too low, and that 10 per cent. a year should be allowed.

The generators and engines may be in a very good condition at the end of ten years, but in the course of that time there would have been so much advance made in the design, economy efficiency and style of mechanical and electrical apparatus that they would probably be able to afford to throw away the original installation. If this holds good regarding engines and dynamos it probably would be more true of storage batteries.

I do not wish anyone to think that I am not in favor of storage batteries. Three years ago when Mr. Arnold had occasion to install the first large storage battery plant in this city in the building of the Board of Trade, I did not think that it would be a success. I was, however, one of the first to compliment Mr. Arnold on the great success of this installation. We should, however, not deceive ourselves and our clients by allowing only two per cent. for depreciation. Let us come right down to facts, and estimate ten per cent. for depreciation of storage batteries, and other apparatus, and an additional four to six per cent. for wear and tear. I would like to hear the opinion of some of the other members on this subject.

MR. APPLETON:—I want to say a few words in reply to those remarks, for I do not think I have made myself perfectly understood perhaps. In the depreciation of an engine or piece of machinery at the end of ten years, a certain amount of money, possibly a great deal, may have been spent for repairs, but you still have the same main parts of the engine and machine as when you started. Now, if you put in a storage battery, at the end of ten years even with six per cent. depreciation you probably won't have the same plates that you started with; you have an entirely new set of plates. Now, if there have been any improvements made in that time you are enabled to get the benefits of those improvements for the same amount of depreciation. The case is entirely different from the repairs and maintenance of any machinery such as engines, boilers or dynamos.

MR. COSTER:—Do you not expect, in the course of ten years to have something in storage batteries a great deal more efficient and better than you have to-day?

MR. APPLETON:—Well, we will have, and still, as I say, the only parts remaining will be the tanks and electrolyte.

MR. COSTER:—How do you know that you will need any tanks after ten years?

THE CHAIRMAN:—Mr. Knox, the Electrical Engineer of the Chicago City Railway Company, is with us, and I am sure that we shall be pleased to hear from him, as among the people that are directly interested in the question of the application of the battery to railway work.

MR. G. W. KNOX:—I came here merely to listen and learn. I will say, however, that in my case, as with most people, first impressions are often the most lasting. I mean by this that about the time I started in railway work I was sent to Dubuque, Iowa, to replace a storage battery road, which had proven unsatisfactory, with the overhead system. and that rather influenced me in thinking that the storage battery was not exactly what was wanted in street railway work. I will say, however, that at this time I am inclined to be a little more liberal, as there have certainly been great developments in the application of the storage battery, more particularly, in central station work, and of late in the railway field. I have been watching with great interest the developments along this line.

I can not agree with Mr. Dow in believing that it will pay to install a small battery at the ends of trolley lines to take care of the fluctuations. It will take some research and close estimating to see where the economy will come in. Although the efficiency of our motors is lowered as our voltage out on the line drops, it really does no particularly harm to the motors to run for a brief period at the lower voltage, even with a drop on the line as high as 15 per cent. So as I was saying, I believe it will take some close estimating to see where by the installation of the small battery to take up the fluctuations it will be found a paying investment.

Mr. Arnold:—I would like to ask Mr. Knox whether in the distribution system of the railway company which he represents, the drop of 10 or 15 per cent. is the total drop from the power station.

Mr. Knox:—No. The drop on line.

Mr. Arnold:—If not, what is the probable maximum?

Mr. Knox:—I have places on the line where I have to take care of as high as a 20 per cent drop. This of course is bad practice. But there is a condition that governs this state of affairs, inasmuch as we are short on the required conduit room, and we are also limited on the street where we carry our overhead wires as to their number, and on account of the liability of change of conditions in the system of distribution we do not know just at this time whether it is policy to figure on running any more feeders to the point where we have the 20 per cent. drop to take care of it. I refer to the Clark street line. But as a whole, outside of the Clark street line, we haven't on our system after a thorough test, over a seven or eight per cent. average drop This represents the maximum average, the general average ranges as low as $6\frac{5}{10}$ per cent. Of course we run a great deal of copper, and we have what we believe to be the most approved rail return in the shape of cast weld joints and immense quantities of copper cables, resulting in the saving of a great deal of the drop usually found in railway work.

Mr. Dow:—I would like to ask Mr. Knox whether those drops are averages, or whether they are the maximum.

Mr. Knox:—I refer to the eight per cent. as the maximum average.

Mr. Dow:—And that covers the instantaneous drop, for instance, resulting from starting several cars simultaneously.

Mr. Knox:—Oh, no.

Mr. Dow:—What is it under those conditions?

Mr. Knox:—Well, we get 12 to 15 per cent.; no more than that.

Mr. Arnold:—I think, Mr. Chairman, that the railway which Mr. Knox represents is particularly well located to keep its average loss so low. Take the case of a long-distance road where the power station is quite a distance from each end of the line. I think it would take a great deal of copper to keep the average drop up to anywhere near the figures given by Mr. Knox. But with power stations located somewhere near the center of a radiating system you would have a condition which would make it possible to hold the voltage up as Mr. Knox states. I think in the long-distance scheme that the regulating battery is required at the end of long feeders.

The Chairman:—As Mr. Appleton will probably be more familiar with the subject matter of this paper than the rest of us I would like to ask for our information regarding these watt-hours per pounds of coal. On page 50 of the paper I under-

stand that the theoretical cost of operation, with a storage battery, is figured on the basis of 557 watt-hours per pound of coal, and that the result obtained from figuring on this basis is compared on the next page with the actual results obtained in practice. No statement is made as to how many watts were obtained from a pound of coal *in practice*. Of course I suppose they get just about half that result; that is to say, they would get about half as good a result as in the theoretical case.

MR. DOW:—We figure a horse-power indicated for 1.12 pounds of coal, which is a little too good.

THE CHAIRMAN:—I figured it over as the paper was being read and made it about 1.20 lbs. I think it would be fair to figure the combined efficiency of a generator set at not over 87 per cent.

MR. DOW:—I figure it 85 per cent.

MR. APPLETON:—I may say, Mr. Chairman, I am not very familiar with the figures given in the paper.

MR. DOW:—I think there is a decimal missing there, Mr. Chairman.

THE CHAIRMAN:—As I understand the paper, the cost of producing the power on that basis is compared with results which were actually obtained in practice. The author of the paper, on page 48 criticizes Mr. Conant and says that none of his stations showed better than 3 pounds per killowatt hour. Now, take 15 tons of coal, running on a basis of 3 pounds of coal per kilowatt hour, and those figures would show a conclusion quite different from what the author seems to have drawn.

Now I would like to ask another question: The author of this paper has stated what he figures to be the cost of the generating plant complete, including stations, at $100 per kilowatt. I think we would all be interested in knowing at what price he has figured the battery per kilowatt in making the comparison.

MR. ARNOLD:—He says distinctly without batteries.

THE CHAIRMAN:—Yes, but in other places he has compared, without giving figures, the cost of the plant with and without batteries.

MR. ARNOLD:—The price entirely depends upon the rate of discharge required of the battery. It may vary from $40 to $175 depending upon the rate.

THE CHAIRMAN:—Per kilowatt hour?

MR. ARNOLD:—Yes.

THE CHAIRMAN:—To what variation do those figures correspond?

MR. ARNOLD:—The price of a battery depends entirely upon the time in which you take its capacity out of it. In other words, if you discharge a battery in one hour you only get about one-half as much out of it as you would if you discharged it over a period of eight hours, so that its price would be double what it

would be at the eight hour rate; so that when you figure batteries at so much per kilowatt hour you must know at what rate you expect to discharge. If they can be discharged over the entire period of eight hours they can be brought down as low as $40 per kilowatt hour. Prices are advancing now, and as I am not in the battery business at present, I am not absolutely sure of present figures but we have figured them as low as $35 per kilowatt hour. If you go up to the one hour rate I think it will be as high as $100, and perhaps in some cases on a half hour rate the figures which I stated a moment ago, $175. There are curves in existence which I had a hand in the preparation of, by which you can tell the cost of a battery if you determine the rate at which you want it discharged. It varies from $35 up.

Mr. Appleton:—With regard to the question which Mr. Dow raised about the regulating effect of a "small" battery, I have a case in mind now where a "small" battery is put at the end of a long feeder nine miles away from the power-house. A sub-station has been built at that distance from the power-house on a line extending about three or four miles beyond, and about three miles back towards the power-house. The maximum amount of current delivered from that power-house reaches as high as 1,000 amperes, but the average during the day is about 400 amperes. This 400 amperes is sent up over a feeder to the battery and is distributed as the load requires at any rate up to 1,000 amperes, the average amount being sent up of course instead of the maximum. The question of the regulating effect of batteries on railway loads is a very interesting one, especially as regards the efficiency of the battery and the amount of work actually done by the battery under such conditions.

Under those conditions the efficiency of the battery is high, because the charge and discharge are intermittent, and you are working the battery under the most efficient conditions. The amount of charge put into the battery is recorded by a wattmeter, and the amount taken out of the battery is recorded by a separate wattmeter, and the average monthly efficiencies are from 90 to 95 per cent., according to the care with which the charging is watched. This battery is given a little charge every night during the hours of light load, and if the men are careful to stop the charge or reduce the charge when the battery is full, the efficiency will reach as high as 95 per cent. in watt efficiency. That, of course, is very different from a battery which is entirely discharged at one discharge and then charged up again. In that case, the efficiency of course is not over 75 per cent.

The Metropolitan Street Railway Company in New York has really installed two large batteries that are not only for regulating purposes, but also for the purpose of taking a portion of the peak; they have one battery installed at the foot of West 23rd street, and there the peak in the afternoon lasts from about 4

until about half past 6, and the work done by the battery during that time is very interesting. Taking one day the maximum rate reached during that two hours and a half is 2,400 to 2,600 amperes. That is the maximum rate at which the battery discharges during that time. Yet the total amount of work done by the batteries during that two hours and a half does not exceed about 1,800 ampere hours, or an average for the two hours and a half of between 700 and 800 amperes discharged.

I have in mind another small station operating five cars supplied entirely by a rotary transformer. When the five cars are running, the fluctuations of course are very great. The maximum demand on the line is about 300 amperes, but that does not occur very often. At that time the maximum load on the rotary is about 100 or 125, or less than one-half, and the average load on the generator is about 80 amperes.

This shows very clearly how the battery used as a regulator in that way, will reduce the required capacity of generation on a rotary transformer. It think it is in this field particularly where the large use of storage batteries will be, as the use of rotaries has come into vogue so extensively.

The use of storage batteries at the power-house is of course different. But by the use of the battery at the feeder end you not only get an equalization of the load on the power-house, but you make a saving in the investment in copper. Whereas, with the battery at the power-house you use it for the better evening up of the load on the generator.

The whole question of the use of batteries for this purpose is best studied in the actual operation of a plant after the battery is put in. In laying out for the use of a battery in work of this sort you can see many advantages, but there are others which are peculiar and particular to each condition, which are not fully realized until you get the advantage of operation. It has been my experience that those in actual charge of the operation always find many more advantages and very different ones than those they were expecting when the plant was put in, and it is due to that as much as anything, I believe, that the use of the storage batteries is growing so in connection with this work.

Mr. Arnold:—I think, Mr. Chairman, that one of the points brought out by Mr. Appleton is very important. I think that Mr. Appleton himself has only recently found it out—within the last few months I mean—and he is the only man who is in a position to find it out, and we are very fortunate in having him make it clear to us. That is the increased efficiency of a regulated battery over and above what we have always supposed it to be. We have always thought that if we got an efficiency of 80 per cent. out of a battery we are doing pretty well. Now Mr. Appleton informs us that the efficiency of the battery under those circumstances is as high as 95 per cent., and he backs the statement with tests which he has made, and the monthly records

of the charging and discharging of the battery. That certainly puts the battery on a much higher plane for one of the main purposes that it has always been advocated for; that shows that it is a remarkably efficient piece of apparatus, and that it is now in the same class as the static transformer or the rotary converter—getting in very good company.

Mr. Dow:—Do I understand that the battery was discharged at quite a high rate and it was charged at short intervals?

Mr. Appleton:—The average current coming over that field was only 400 amperes, and therefore the rate of charging could not exceed 400. But the rate of discharge would be 600 at the the time of maximum load, and the thousand amperes or 400 amperes coming up over the feeder would be distributed as needed from the battery, making the total output 1000 amperes, that is, at moments of fluctuation caused by the cars getting bunched, coming up a hill, or something of that sort.

The Chairman:—What would be the capacity of that battery based on the ordinary eight-hour discharge.

Mr. Appleton:—The battery has an hour rate of 600 amperes or 1200 amperes at an eight-hour rate.

The Chairman:—That is all right.

Mr. Appleton:—Then we really would be charging and discharging simply as the load varies.

The Chairman:—But at quite a high rate as compared with the figures that are ordinarily given for charging and discharging.

Mr. Appleton:—No, sir, the average load on that section never falls below about 200 amperes, therefore the battery hardly ever charges above 200 amperes, and that you see for a short time. The load in that section would never fall down to nothing. If it did fall down to nothing the rate of charge would be 400 amperes during that time, as 400 amperes is the ordinary current being sent up to that section over that feeder.

The Chairman:—But a charge or discharge of 200 amperes on the battery.

Mr. Appleton:—I say a charge of 200 and a maximum discharge of 600.

The Chairman:—Well, that rate of charge and discharge on a battery of the capacity of only 1200 ampere hours at the eight-hour rate, would really be a high rate, would it not?

Mr. Appleton:—It is only the one hour rate battery now, sir, which I think is almost universal for regulating work of that sort.

The Chairman:—What I am trying to get at is, that this high efficiency which you get is due to the intermittent work on the battery. If it was charged and discharged at anything like that rate constantly you would not get that efficiency.

Mr. Appleton:—Certainly not, because the charge and discharge are not continued long enough to allow the voltage of the

battery to drop down in discharging or raise in charging to any appreciable extent. It does not give time for the gas to form on the plate. On the other hand, the discharge is not continued long enough to allow a great drop.

THE CHAIRMAN:—So that it is operated with the same advantage that you would get with an open circuit primary battery.

MR APPLETON:—Of course. The internal resistance of a primary battery would be so great that if any work was done at all it would drop down, but the internal resistance of the storage battery is so low that a discharge for a short time hardly decreases it at all. Your discharge is almost the same as an open circuit under those conditions. As a matter of fact batteries in regulating duty of this sort, work at an average of 2.08 volts. That is not the same value they would have if worked at a steady discharge extending over eight or ten hours.

THE CHAIRMAN:—The real work being on the straight part of the curve all the time, they don't get the loss that you get on the rise and fall, which is a great portion of the loss.

MR. APPLETON:—That is it exactly.

MR. DOW:—This variation was in watts.

MR. APPLETON:—Yes, as measured by a wattmeter.

MR. DOW:—As a mere matter of curiosity would you tell us what the ampere efficiency would be?

MR. APPLETON:—Well, in that connection I couldn't tell, sir, because we never measured it. I would say about two per cent. higher.

MR. DOW:—Then that demonstrates that the variation of voltage is very small.

MR. APPLETON:—It is very small indeed. You are operating almost at a constant voltage under these conditions.

Of course there is one point I would like to add in connection with that statement: That in order to obtain the best results, the number of cells must be very carefully adjusted to the average voltage at that point. If you have too few cells the battery will of necessity overcharge and destroy the efficiency.

[Adjourned subject to the call of the Secretary.]

AMERICAN INSTITUTE OF ELECTRICAL ENGINEERS.

March 22nd, 1899.

The 133rd meeting of the INSTITUTE was held this date at 12 West 31st street and was called to order by President Kennelly at 8:25 P. M.

THE PRESIDENT:—The Secretary will read the announcements for the evening.

THE SECRETARY:—At the meeting of Council this afternoon the following associate members were elected.

Name.	Address.	Endorsed by
GREGG, TOM HOWARD	Supt. Electrical Construction, U.S. Light House Board, Tompkinsville, S. I., N. Y., residence, New Brighton, S. I.	Leroy Clarke, Jr. O. R. Roberson. J. D. Bishop.
HORN, HAROLD J.	Electrical Engineer, John A. Roebling's Sons' Co., residence, 36 W. State St., Trenton, N. J.	J. H. Klinck. H. S. Webb. W. S. Franklin.
JOHNSON, HOWARD S.	Engineer and Sales Agent, Morgan-Gardner Electric Co., residence, 70 Jefferson Ave, Columbus, O.	Fred'k Bedell. Harris J. Ryan. H. S. Rogers.
MILLER, HERBERT S.	Electrical Engineer, Diehl Mfg. Co., residence, 1025 E. Jersey St., Elizabeth, N. J.	E. H. Bennett. Philip Diehl. Ralph W. Pope.
POMEROY, WILLIAM D.	Electrician, Akron Electric Mfg. Co., 1106 So. Main St., Akron, O.	H. J. Ryan. Chas. S. Brown. F. W. Phisterer.
WHITTED, THOS. BYRD	Electrical Tester, The General Electric Co., residence, 211 State St., Schenectady, N. Y.	A. L. Rohrer C. P. Steinmetz. Theo. Stebbins.

Total 6.

The Council, in accordance with the Constitution, canvassed the returns from nominations and selected the following Council nominees for the coming election.

FOR PRESIDENT:—Dr. Arthur E. Kennelly.

FOR VICE-PRESIDENTS:—J. W. Lieb, Jr., Charles F. Scott, and L. B. Stillwell.

FOR MANAGERS:—C. O. Mailloux, S. Dana Greene, C. S. Bradley, W. D. Weaver; and in place of W. F. C. Hasson of San Francisco, who has resigned on account of removing to the Hawaiian Islands, Dr. F. A. C. Perrine has been appointed by Council to fill out the unexpired term of one year.

FOR TREASURER:—George A. Hamilton.

FOR SECRETARY:—Ralph W. Pope.

The following Local Honorary Secretaries were appointed:

For Great Britain, H. F. Parshall, London; for Australasia, J. S. Fitzmaurice, Sydney, N. S. W.; for Canada, Prof. R. B. Owens, Montreal.

THE PRESIDENT:—The business of the evening will be the consideration of a paper by Prof. Pupin on the "Propagation of Long Electric Waves." We have the pleasure of Prof. Pupin's presence and will ask him to come forward and present the paper.

A paper presented at the 133d Meeting of the American Institute of Electrical Engineers, New York, March 22, 1899. President Kennelly in the Chair.

PROPAGATION OF LONG ELECTRICAL WAVES

BY M. I. PUPIN

INTRODUCTION

This paper describes an experimental method of investigating the propagation of long electrical waves and discusses the mathematical theory bearing upon the same.

The study of the propagation of electrical waves received a powerful impulse by Hertz's discovery of a method of producing waves the length of which could be conveniently measured within the space of a laboratory. The oscillations which emit such waves are of very high frequency; in the vicinity of a thousand million vibrations per second.

In telephony, telegraphy, and long-distance transmission of power, oscillations of only several hundred vibrations per second, or even less than one hundred are employed. The waves accompanying these slow vibrations are hundreds of miles long. It seems, therefore, a hopeless task to undertake to device an experimental method which will do for these excessively long waves what the Hertzian method has done for short waves, the so-called Hertzian waves. This explains the singular fact that whereas there is an extensive mass of experimental facts which throw much light upon the mathematical theory of the Hertzian waves *there is to-day scarcely a single experiment which can throw any light upon the mathematical theory of long electrical waves.* The experiments described in Section III. of this paper are, therefore, the first experiments of this kind on record.

It appears at first sight as if there should be no difference between the mathematical theory of short waves and that of long waves, and that whatever throws light upon one should illumin-

ate the other also. But this difference does exist, and it is due to the fact that the Hertzian waves are waves emitted by free oscillations, whereas the long waves employed in telegraphy, telephony, and long-distance transmission of power, are due to forced electrical oscillations. The one theory deals, therefore, with free, and the other principally with forced electrical oscillations. Besides, these long waves proceed generally from a terminal apparatus of large impedance and the principal object in transmitting them is to have them absorbed in a receiving apparatus of large impedance. The question : How much of the energy transmitted at one end is received at the other end? is the principal question in the mathematical theory of long waves. The experimental researches which have done so much for our clear understanding of the propagation of the Hertzian waves can, therefore, help us but little in the advancement of our knowledge of the mathematical theory of propagation of electrical energy for telegraphy, telephony, and long-distance transmission of power.

The shortness of the wave-length makes the Hertzian oscillations manageable, the excessive wave-length makes, apparently, the experimental investigation of the propagation of slowly alternating electrical vibrations a practical impossibility. But does a long period necessarily mean a long wave? The wave-length of sodium light, for instance, is shorter in glass than it is in vacuum, because light travels more slowly in glass than it does in vacuum. If we could increase the index of refraction of glass to anything we please, we could correspondingly diminish the wave-length. It is all a question of velocity of propagation. Now the simplest manner of viewing this velocity is that devised by Fresnel. He constructed over the same base in the boundary surface between the two media under consideration two cylinders parallel to the ray, one cylinder extending into the vacuum and the other into the glass. Let the heights of these two cylinders be each equal to the velocity of propagation in the two media, then whatever radiant energy was in one of the cylinders at any given moment will be in the other after the lapse of one second. The velocity of propagation is, therefore, proportional to the amount of energy which the medium stores up per unit length of the rectilinear path of the ray, when a given stress is propagated through it. If in place of glass we interposed in the path of the ray a substance which could store up one million times as much energy per unit length of

rectilinear path as the vacuum can when the same ray is propagated through them then we should have the velocity and therefore the wave-length also one million times smaller in this medium than in vacuum.

This very thing can be done in the case of electrical waves. Consider a coil represented in Fig. 6.

It consists of a certain number of layers of copper wire wound in the following way:—After winding a layer of wire, a sheet of tinfoil is wrapped around this layer; the next layer is then wound and again a sheet of tinfoil wrapped, and so on. The tinfoil layers are connected in series to each other and then grounded through *c*. Everything is adjusted in such a way that the coil when completed has the same coefficient of self-induction, the same capacity, and the same resistance, as a first-class telephone wire ten miles in length. The distance between the faces of the coil is three inches. Such a coil is capable of storing up as much of the energy of a given electric wave as a long-distance telephone wire 10 miles in length can, hence interposing such a coil in the path of an electric wave will make the wave advance through a distance of three inches only in the same time during which it would pass over ten miles on the telephone wire. Connecting 24 such coils in series we have a loop which is in *every particular* equivalent to a loop of long-distance telephone wire 240 miles in length. An electrical wave will be propagated along it in just the same way as along the telephone line, with no other modification except that which a ray of light experiences in passing from a vacuum to a denser medium, and that is, a smaller velocity and therefore a shorter wave-length. A wave-length of, roughly, 140 miles corresonds to a frequency of about 1,000 periods per second when the wave advances along the telephone line now in use between New York and Chicago. Now 140 miles of a telephone air line correspond to 14 coils and therefore the same wave advancing through the coils would develop its whole wave-length within these 14 coils. The wave takes a spiral path. The axis of the spiral equals the length of the 14 coils, that is three and a-half feet. The rectilinear velocity of the wave and therefore its rectilinear wave-length have been reduced over two hundred thousand times.

Such a *slow-speed conductor* is an exact representation of a medium possessing an excessively high index of refraction and offers a new and convenient method of producing short

waves even for very long periods of oscillation. It brings, therefore, the phenomena of propagation of long electrical waves within the reach of laboratory investigation. Such, briefly stated, is the new experimental method which forms the subject of this paper. The matter is discussed fully in Section III.

The scientific interest attached to experimental investigations of this kind needs no further commentary. Their practical utility will be evident when one considers that very many practical problems in telegraphy, telephony, and long-distance transmission of power depend on experimental investigations of this sort. Muirhead's artificial cables have helped much to advance the art and the science of submarine telegraphy; the slow-speed conductor described in this paper will, it is hoped, do for land lines as much as Muirhead's artificial cables have done for submarine cables.

The slow-speed conductor just described was constructed over four years ago in the electro mechanical laboratory of Columbia University. It was a home-made affair and although adjusted with the greatest care it developed a certain objectionable feature which those skilled in the art of manufacturing condensers could have foretold with certainty. Its capacity and leakage constant varied considerably and it could not stand a high voltage, not higher than 500 volts. To overcome this difficulty a new form of slow-speed conductor represented in Figs. 10 and 11 was constructed. This form is called a *loaded conductor*. In how far the mathematical theory of electrical propagation given in Sect. I is applicable to such a conductor had to be shown. This is done in Section II, where two arrangements are discussed and it is shown that a conductor of this kind consisting of 400 sections, each section having the same coefficient of self-induction, the same capacity, and the same resistance as a long-distance telephone wire of $2\frac{1}{2}$ miles in length is equivalent to a loop of such a wire of 1,000 miles in length for all frequencies which are of any importance in telegraphy, telephony, and long-distance transmission of power by machinery designed to generate electromotive forces of frequencies which are now generally employed. This part of the mathematical theory contained in this paper is believed to be new. The other part, contained in Section I, is, of course, not altogether new. That which is considered novel and important should be stated here briefly, for

the purpose of elucidating beforehand the plan of this somewhat lengthy essay.

The most essential elements in the mathematical theory of electrical wave propagation are contained in the answers to the following two questions:—

First Question.—What variation does the wave energy undergo during its propagation from the transmitting to the receiving apparatus?

The mathematical theory given in Section I. of this paper answers this question by constructing the mean electro kinetic energy curve for two most important, and, at the same time, most general cases. In the first case the effect of the transmitting apparatus alone is considered, in the second case the effects of both the transmitting and the receiving apparatus are taken into consideration. In the first case the mean electro-kinetic energy curve (Fig. 2) consists of the superposition of a simple harmonic upon a catenary, in the second case Fig. 3 this curve consists of the superposition of a double harmonic upon a double catenary. The mechanical illustration of this result is extremely simple and seems to have escaped the notice of previous mathematical investigations. In the first case the curve can be illustrated by the forced vibration of a heavy string which is stretched by a certain tension between two points on the same horizontal line. In the second case the mean electro-kinetic energy curve finds a striking illustration in the forced vibration of a heavy string stretched by a certain tension between two points on the same horizontal line and carrying a weight at its middle point. An experimental investigation described in Section III. led to the conclusion that this is one of the most striking features of the propagation of long electrical waves and the theory in Section I. as formulated in such a way as to give a strong emphasis to this interesting feature. This is one of the elements which is considered important and novel in the mathematical theory of Section I.

Second Question.—What are the means which the theory suggests for measuring the wave-length and the velocity of propagation of long electrical waves which accompany forced electrical oscillations?

The mathematical theory given in Section I. answers this question. It shows that having plotted the mean electro-kinetic energy curve by measurements which involve the use of an

ordinary ammeter or voltmeter the wave-length can be determined from this curve by measuring the distance between two sharply defined minima. From the wave-length and the known period the velocity of propagation can be calculated. This experimental method is essentially the same as the one which Hertz employed for rapid oscillations. It could not conveniently be applied to ordinary telegraph and telephone lines, but applied to a "slow-speed conductor" it enables us to measure the quantities just mentioned with as high a degree of accuracy as may be desired, in fact the method becomes with such a conductor more direct than, and at least as accurate as, the Hertzian method, provided, of course, that one has an accurately constructed slow-speed conductor at his disposal. This is the second element which is considered important and novel in the mathematical theory of Section I.

There are two more motives which influenced the formulation of the mathematical theory of Section I. and which should now be mentioned. The less important one will be mentioned first. It is clear that equation (6) of this section is the most comprehensive mathematical statement of this theory. It is the general solution of the equation of propagation. From it the forced as well as the free oscillations are deduced in this paper. This general solution was stated in that particular form, because the general solution of the differential equations of electrical oscillations on a "slow-speed loaded conductor" discussed in Section II, is of the same form, so that a comparison of the two cases can be readily made.

The second motive concerns what may be called the physical aspect of the mathematical theory of wave propagation along conducting wires. Most of the mathematical investigations dealing with this subject are purely symbolic. Mr. Oliver Heaviside has done much to introduce the living language of physics in place of the sign language of mathematical analysis. But Mr. Heaviside's English is often much clearer than his Arithmetic, such at any rate seems to be the general impression, so that much remains yet to be done even after Mr. Heaviside's most brilliant epoch of intense activity and radical reforms in the field of long wave propagation. That which remains to be done is not so much on the purely mathematical side of it, for that is pretty well understood now, and has been so ever since the time of Lagrange and Fourier. It is the physical side of the theory which

needs cultivation. The time seems to be ripe for looking upon the problems of electrical wave propagation somewhat in the same manner in which the physical theory of light views the phenomena of radiation, reflection, interference, and absorption. According to this view the transmitting apparatus is a source of radiation, the receiving apparatus is a boundary of secondary radiation due to reflection of the wave energy which arrives there; the wave on the line conductor is an interference wave, the components of which are the direct wave from the transmitting end and the reflected wave of the receiving end. The power absorbed by the receiving end is equal to the difference of the wave energy which arrives there and the energy which is reflected per unit of time. Then again there is energy absorbed all along the line which interferes with the efficiency of transmission. *To reduce this absorption to a minimum without increasing the cost of the line beyond prohibitory limits is the ultima thule of long-distance electrical transmission engineering.* This problem contains the most essential point in the whole theory of electrical wave propagation for telephony, telegraphy, and other purposes. A mere mathematical solution of the equation of propagation does not shed much light upon this side of our theory; a careful physical consideration of the matter will supply the deficiency. Thus, the power absorbed in any element of the line depends upon the angle of lag between the current, and the potential gradient or electromotive intensity in that element. Such is the physical view of propagation of light through absorbing media. This angle depends upon the ratio of reactance to resistance of the element and we have at once the *simple rule that an efficient transmission requires a line in which the reactance per unit length should be large in comparison to the resistance.* In other words the power factor of the line should be as small as possible. The ideal line acts like a perfectly transparent medium. At every point of such a medium the electric force and the magnetic force differ in phase by a quarter period. The introduction of these elements into the theory of Section I. forms another novel feature of this section, and this introduction seems to simplify both the mathematical form and the physical aspect of the theory very much.

To bring this theory within the reach of those who mostly need it, and that is telegraph and telephone engineers, is one of the principal aims of this paper. Hence its somewhat didactic form.

SECTION I.[1]

ELECTRICAL OSCILLATIONS ON A LINEAR CONDUCTOR OF UNIFORMLY DISTRIBUTED CAPACITY, SELF-INDUCTION, AND RESISTANCE.

The conductor is a loop of wire A B (Fig. 1). At one point of the loop is a transmitting apparatus A, at the diametrically opposite point is a receiving apparatus B. The distance between A and B is l, equal to one-half the length of the whole loop. The distance of any element ds from A is denoted by s.

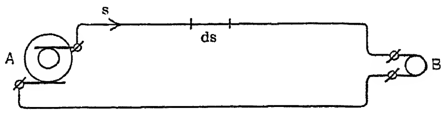


FIG. 1.

GENERAL SOLUTION OF THE PROBLEM.

§ 1. Let L, R, C, be the coefficient of self-induction, the ohmic resistance, and the capacity, respectively, per unit length of the line. Let y be the current and V the potential at any element ds, then by putting the sum of reactions in ds equal to zero, in accordance with the law of equality of action and reaction, we obtain

$$\left(L\frac{dy}{dt} + Ry + \frac{\delta V}{\delta s} \right) ds = 0 \tag{1}$$

An observation should now be made which is usually overlooked. In forming this equation the dissipative reactions set up in the neighboring conductors have been neglected. The inaccuracy thus introduced is small for air lines. In the case of submarine cables the errors arising from this may be considerable.

If x be the displacement current, then

$$x = C\frac{dV}{dt} = -\frac{\delta y}{\delta s} \tag{2}$$

From (1) and (2) we obtain the equation of propagation :—

$$L\frac{d^2y}{dt^2} + R\frac{dy}{dt} = \frac{1}{C}\frac{\delta^2 y}{\delta s^2} \tag{3}$$

The current is propagated in form of a plane wave. The

1. This section read before the *American Mathematical Society*, February meeting, 1896.

velocity of propagation v, neglecting the effect of the resistance R, is given by

$$v = \frac{1}{\sqrt{L\,C}}$$

Arbitrary conditions:—The equation of propagation was deduced from (1). This last equation is a mathematical expression of the law of equality of action and reaction at any point of the line where the uniformity of the line is not disturbed by the interposition of transmitting or receiving apparatus. But at points where such apparatus exists the mathematical expression for the law of equality of action and reaction is different from (1) and has to be determined from physical considerations in each particular case. At such points the equation of propagation will be modified. There are evidently as many of these subsidiary equations as there are points of discontinuity on the line. They are said to express the *boundary conditions* at these points. The mathematical function for the current y will have to satisfy not only (3) but also every one of the boundary equations. The conductor discussed here has two such points, A and B. The arbitrary conditions entering into our problem will be completely specified if we know the manner in which the electromotive force generated at A is impressed upon the line and if, in addition, the constants of the circuit in the transmitting and in the receiving apparatus are given. This will be done now.

Generator at A impresses an electromotive force

$$e = f(t)$$

where $f(t)$ is some analytical function of t.

The electro-magnetic constants of the circuit at A and B are as follows:—

L_0, R_0, C_0, and L_1, R_1, C_1, are the effective co-efficient of self-induction, the effective resistance, and the capacity of the transmitting and of the receiving apparatus, respectively.

This fixes the arbitrary conditions and we can proceed now to deduce the equations, which express the boundary conditions.

Let V_0 be the potential at $s = 0$

" V_{2l} " " " " $s = 2\,l$

Let $\left\{\begin{matrix} V_l \\ V'_l \end{matrix}\right.$ " " " " $s = l$

Where V_l is the potential at that terminal of the receiving apparatus which is nearest to point $s = 0$ and V'_l is the potential at the other terminal.

Let P_0 be the potential difference in condenser C_0.

Let P_1 " " " " " . " C_1.

Stating the law of equality of action and reaction for the terminals of A and B we obtain the following two equations expressing the so-called boundary conditions:—

$$\left.\begin{aligned} &\left[L_0 \frac{dy}{dt} + R_0\, y + P_0 + V_0 - V_{2l}\right]_{s=0} = f(t) \\ &\left[L_1 \frac{dy}{dt} + R_1\, y + P_1 + V'_l - V_l\right]_{s=l} = 0 \end{aligned}\right\} \quad (4)$$

It should be observed here that we infer from purely physical considerations that the potential V is discontinuous at $s = 0$ and $s = l$. In a symmetrical system, like the one before us, the discontinuity amounts to this:

$$V_0 = - V_{2l}$$
$$V_l = - V'_l$$

In other words

$$V = - V'$$

where V is the potential at any point between $s = 0$ and $s = l$
and V' " " " " " " " $s = l$ and $s = 2\,l$

It is also a matter of purely physical considerations which leads us to assume that y is a function which is continuous all along the line.

The physical meaning of the problem suggests the following solution:

$$y = (K_1 \cos m\,\xi + K_2 \sin m\,\xi)\, e^{k_1 t} \quad (5)$$

where $\xi = l - s$ and the origin of co-ordinates is thus transferred to the point where the receiving apparatus is located.

This will satisfy (3) provided that

$$- m^2 = k_1\, C\,(k_1\, L + R)$$

Solution (4) contains three arbitrary constants. K_1, K_2, and k_1, as many as the number of existing arbitrary conditions.

These constants are selected so as to satisfy (4). This is done by inserting the value of y from (5) into (4) and determining K_1 K_2 and k_1 so as to satisfy this equation. It is evident that $k = k_1$.

To calculate K_1 and K_2 introduce the following abbreviations:—

$$\lambda_0 = L_0 + \frac{1}{k^2 \; C_0}$$

$$\lambda_1 = L_1 + \frac{1}{k^2 \; C_1}$$

$$h_0 = k \; C \, (k \; \lambda_0 + R_0)$$

$$h_1 = k \; C \, (k \; \lambda_1 + R_1)$$

$$D_0 = k \; C \; E.$$

The following values for K_1 and K_2 are obtained from the two boundary equations:—

$$K_1 = \frac{2 \; m \; D_0}{F}$$

$$K_2 = \frac{h_1 \; D_0}{F}$$

where

$$F = (h_0 \; h_1 - 4 \; m^2) \sin m \; l + 2 \; m \; (h_0 + h_1) \cos m \; l$$

and equation (4) can now be written

$$y = [\, 2 \; m \cos m \; \xi + h_1 \sin m \; \xi \,] \; \frac{D_0 \; e^{kt}}{F} \tag{6}$$

This is the most general solution of our problem. It includes both forced and free oscillations.

Forced Harmonic Oscillations.

§. 2 Harmonic oscillations maintained by the action of an alternator impressing a simple harmonic E.M.F. upon the line are of universal interest and will be considered here. They are employed in experimental investigations and in industrial arts. In

this case the impressed E.M.F. is the real part of $E e^{ipt}$ and the current will be the real part of y in (6). We shall have now

$$-m^2 = -(\alpha + i\beta)^2 = ip\,C(ipL + R)$$

$$\therefore \ \alpha = \sqrt{\frac{pC}{2}[\sqrt{p^2L^2 + R^2} + pL]}$$

$$\beta = \sqrt{\frac{pC}{2}[\sqrt{p^2L^2 + R^2} - pL]}$$

Three distinct cases arise which will be discussed in turn. It is well to state here that the discussion will be conducted in all cases in accordance with the following programme:—

First, we shall inquire how the available energy varies during its propagation between the transmitting and the receiving end; *secondly*, what is the wave-length and the velocity of propagation; and *thirdly*, does the theory indicate a practicable method of measuring the wave-length and the velocity of propagation. These are evidently the essential elements which enter into the description of wave propagation.

First case.—The impedance of the transmitting and of the receiving apparatus is negligibly small:—This is the simplest case and is generally considered in elementary treatises.

We have

$$h_0 = h_1 = 0$$

Hence

$$F = -4\,m^2 \sin m\,l$$

$$y = -\frac{ip\,C\,E\cos m\,\xi\,e^{ipt}}{2\,m\sin m\,l}$$

Remembering that

$$\cos m\,\xi = \tfrac{1}{2}[(e^{\beta\xi} + e^{-\beta\xi})\cos\alpha\,\xi - i(e^{\beta\xi} - e^{-\beta\xi})\sin\alpha\,\xi]$$

$$\sin m\,\xi = \tfrac{1}{2}[(e^{\beta\xi} + e^{-\beta\xi})\sin\alpha\,\xi + i(e^{\beta\xi} - e^{-\beta\xi})\cos\alpha\,\xi]$$

We shall have for the real part of y the following:—

$$\eta = \frac{\tfrac{1}{2}E\sqrt{pC}[(e^{\beta\xi}-e^{-\beta\xi})\sin\alpha\xi\cos(pt-\varphi-\psi)-(e^{\beta\xi}+e^{-\beta\xi})\cos\alpha\xi\sin(pt-\varphi-\psi)]}{\sqrt[4]{p^2L^2+R^2}\sqrt{e^{2\beta l}+e^{-2\beta l}-2\cos 2\alpha l}}$$

$$= A\,[e^{\beta\xi}\sin(p\,t - \psi - \alpha\,\xi) + e^{-\beta\xi}\sin(p\,t - \psi + \alpha\,\xi)] \qquad (7)$$

where

$$\tan\psi = \frac{e^{-\beta l}\sin(\alpha\,l - \varphi) + e^{\beta l}\sin(\alpha\,l + \varphi)}{e^{-\beta l}\cos(\alpha\,l - \varphi) - e^{\beta l}\cos(\alpha\,l + \varphi)}$$

$$\tan\varphi = \frac{\alpha}{\beta}$$

Let $\lambda =$ wave-length, then evidently

$$\lambda = \frac{2\,\pi}{\alpha}$$

If T is the period of the impressed E.M.F., then denoting by v the velocity of propagation we shall have

$$v\ T = \lambda = \frac{2\,\pi}{\alpha}$$

On account of this relation α should be called the "*velocity constant.*" If we could measure λ we could calculate v. On this point more will be said in the discussion of the next case.

An experimental exploration of the current along the line would necessarily measure the mean square of the current. There are no instruments which indicate the instantaneous value of a variable current or potential. Besides, this mean square measures the mean value of the available electro-kinetic energy at the point under consideration. Hence it is a most important quantity and its introduction into the propagation theory seems to simplify the apparent complexity of this branch of electro-mechanics.

Let $M\ (\eta^2)$ denote the mean square of the current at any point on the line, then since

$$M\,(\eta^2) = \frac{2}{T}\int_0^{\frac{T}{2}} \eta^2\,dt$$

we shall obtain from (7)

$$M(\eta^2) = \tfrac{1}{8}\frac{E^2 p\,C\,[e^{2\beta\xi} + e^{-\beta\xi} + 2\cos 2\alpha\xi]}{\sqrt{p^2L^2 + R^2}\ [e^{2\beta l} + e^{-2\beta l} - 2\cos 2\,\alpha l]} \qquad (8)$$

The physical meaning of this formula will be discussed in con-

nection with the corresponding expression which will be obtained in the next case.

Second case:—The impedance of the receiving apparatus, only, is negligibly small.

In this case

$$h_1 = 0$$

$$F = -4\, m^2 \sin m\, l + 2\, m\, h_0 \cos m\, l$$

The current is equal to the real part of

$$y = \frac{D\, e^{ipt} \cos m\, \xi}{-2\, m \sin m\, l + h_0 \cos m\, l} \tag{9}$$

It is evident that

$$\frac{D}{-2\, m \sin m\, l + h_0 \cos m\, l}$$

measures the initial amplitude of the wave but does not affect its subsequent variation during its propagation from the transmitting apparatus along the line. Since this variation is the real object of our study, it is superfluous to perform here the actual calculations of the initial amplitude in terms of α, β, l, and h_0. Those interested in the design and installation of telegraph and telephone lines will have no difficulty in performing this task. Much confusion is avoided by keeping these somewhat lengthy and tedious calculations out of the main body of the mathematical analysis of wave propagation. They are not essential and should not be allowed to obscure the view of those elements of the theory which are of fundamental importance.

The amplitude can be written

$$\frac{D}{P + i\, Q} = \frac{D\, e^{-i\psi}}{\sqrt{P^2 + Q^2}}$$

Hence (9) assumes the form

$$y = \frac{D\, e^{i(pt-\psi)} \cos m\, \xi}{\sqrt{P^2 + Q^2}}$$

$$= A\,[(e^{\beta\xi} + e^{-\beta\xi}) \sin(pt-\psi) \cos \alpha\xi + (e^{\beta\xi} - e^{-\beta\xi}) \cos(pt-\psi) \sin \alpha\xi + iX]$$

Hence the real part of y will be

$$\eta = A[e^{\beta\xi}\sin(pt-\psi-\alpha\xi)+e^{-\beta\xi}\sin(pt-\psi+\alpha\xi)] \qquad (10)$$

From this the potential V is easily deduced. Since

$$-\frac{\delta\eta}{\delta s} = \frac{\delta\eta}{\delta\xi} = C\frac{dV}{dt}$$

we shall have

$$V = A_1[e^{\beta\xi}\cos(pt-\psi-\varphi-\alpha\xi)-e^{-\beta\xi}\cos(pt-\psi-\varphi+\alpha\xi)] \qquad (11)$$

$$V_1 = -V$$

where

$$A_1 = \frac{A\sqrt{\alpha^2+\beta^2}}{p\,C} = \frac{A\sqrt[4]{p^2L^2+R^2}}{\sqrt{p\,C}}$$

$$\tan\varphi = \frac{\alpha}{\beta}$$

The displacement current x plays a very important part in telephony owing to the facility with which it will produce cross-talk and thus make itself objectionable. Several devices have been tried in telephony to get rid of this source of annoyance.[1]

The expression for x is easily obtained from the relation.

$$x = C\frac{dV}{dt} \qquad (12)$$

The equations of the mean square curves are now easily obtained.

$$\left.\begin{aligned} M(\eta^2) &= \frac{A^2}{2}(e^{2\beta\xi}+e^{-2\beta\xi}+2\cos 2\alpha\xi) \\ M(V^2) &= \frac{A_1^2}{2}(e^{2\beta\xi}+e^{-2\beta\xi}-2\cos 2\alpha\xi) \\ M(x^2) &= \frac{p^2C^2A_1^2}{2}(e^{2\beta\xi}+e^{-2\beta\xi}-2\cos 2\alpha\xi) \end{aligned}\right\} \qquad (13)$$

Discussion of the equations:—It is evident that the mathe-

1. See J. J. Carty, TRANSACTIONS, vol. viii, p. 100, 1891.

matical relations deduced for the second case are of the same form as those obtained for the first case. The effect, therefore, of the transmitting apparatus upon the wave is to modify its initial amplitude, only, and nothing else. It is sufficient, therefore, to discuss the physical meaning of the results of the second case.

The current wave, equation (10) :—It can be decomposed into two components η_1 and η_2; thus,

$$\eta = \eta_1 + \eta_2$$

$$\eta_1 = A\, e^{\beta\xi} \sin\,(p\,t - \psi - \alpha\,\xi)$$

$$\eta_2 = A\, e^{-\beta\xi} \sin\,(p\,t - \psi + \alpha\,\xi)$$

Each of these components is a progressive wave.

η_2 is maximum at $\xi = -\,l$, and minimum at $\xi = l$

η_1 " " " $\xi = +\,l$, " " " $\xi = -l$

The first wave starts from one pole of the transmitting alternator and describes a right handed motion around the loop. The second wave starts at the other pole of the alternator and travels in the opposite direction. The waves have the same initial amplitude, the same velocity, and they become attenuated at the same rate. The distribution of the wave around the loop is perfectly symmetrical. The resultant current wave η is an interference wave. On account of attenuation the interference is not capable of producing a stationary wave, because when the two interfering waves meet they have unequal amplitudes.

When the resistance per unit length is made small in comparison to the reactance and the line is sufficiently short, the attenuation constant β becomes so small that

$$e^{\beta\xi} = e^{-\beta\xi} = 1$$

and in that case

$$\eta = \eta_1 + \eta_2 = A\,[\sin\,(p\,t - \psi - \alpha\,\xi) + \sin\,(p\,t - \psi + \alpha\,\xi)\,]$$

$$= 2\,A\,\cos\,\alpha\,\xi\,\sin\,(p\,t - \psi)$$

that is, a stationary wave is formed.

But even if the line is long, provided that R is sufficiently small in comparison to pL, as in the case of efficient long-distance telephone lines, the two waves will be nearly equal for quite a distance on each side of the middle point of the loop where in general the receiving apparatus is located. Hence in the vicinity of this point the resultant current wave approximates very nearly the form of an interference wave. This fact manifests itself in an interesting manner and will be brought out presently in connection with the discussion of a method which this theory suggests for measuring experimentally the wave-length and the velocity of long waves.

The potential and the displacement current waves, equations (11) *and* (12):—They are just like the current wave, interference waves, and the remarks just made with reference to the current wave apply to them also. An interesting relation between these waves and the current wave deserves a careful attention. It is the phase-difference φ. This angle measures the attenuation, as will be seen presently.

Efficiency of transmission:—Equation (1) can be written

$$L\frac{d\eta}{dt} + R\eta = \frac{\delta V}{\delta\xi}.$$

The quantity $\frac{\delta V}{\delta\xi}$ should, therefore, be called *the electromotive intensity.* Its value is easily obtained from (11.) Thus

$$\frac{\delta V}{\delta\xi} = \frac{A(\alpha^2+\beta^2)}{p\,C}\left[e^{\beta\xi}\sin(pt-\psi-\alpha\xi+\theta)+e^{-\beta\xi}\sin(pt-\psi+\alpha\xi+\theta)\right] \tag{14}$$

where

$$\theta = -2\varphi + \frac{\pi}{2}$$

The angle θ is the angle of lag between the current and the electromotive intensity as can be seen by comparing (10) and (14). It will be shown now that this angle of lag plays the same part here as the angle of lag between the impressed electromotive force and the current in ordinary alternating current circuits.

Consider the equation

$$W = R\,M(\eta^2) = M\left(\eta \times \frac{\delta V}{\delta\xi}\right)$$

That is to say, the mean value of the work per second done by the electro-motive intensity equals the mean value of the rate of dissipation per unit length of the line. This dissipation causes the attenuation of the wave and thus diminishes the efficiency of transmission. A small value of R will evidently prevent it. But that this efficiency is not a question of ohmic resistance, only, will be seen from the following consideration:

$$\cos\theta = \sin 2\varphi = 2\sin\varphi\cos\varphi = \frac{R}{\sqrt{p^2 L^2 + R^2}}$$

or

$$\tan\theta = \frac{pL}{R}$$

Now let

$$M\left[\left(\frac{\delta V}{\delta \xi}\right)^2\right] = \frac{A_v^{\,2}}{2}$$

$$M(\eta^2) = \frac{A_\eta^{\,2}}{2}$$

Then since

$$M\left[\left(\frac{\delta V}{\delta \xi}\right)^2\right] = (p^2 L^2 + R^2)\, M(\eta^2)$$

we shall have

$$\frac{1}{2}\,\frac{R}{\sqrt{p^2 L^2 + R^2}}\, A_v\, A_\eta = R\, M(\eta^2)$$

$$\therefore\ \frac{1}{2}\, A_v\, A_\eta \cos\theta = R\, M(\eta^2)$$

For efficient transmission we must have, therefore, a large angle of lag between the current and the electromotive intensity. The quantity $\frac{pL}{R}$, that is the ratio of reactance to resistance, is the most essential element, and not R alone, in questions of efficiency of this kind. Employing the terminology which has been generally adopted among electrical engineers, we have the following simple rule:—*The power factor of the line must be as small as possible.* The physical reason for this is not far to seek. A large angle of lag between the electromotive intensity and the current, means the same thing here as it does in ordinary circuits, and that is, it means a large self-induction reaction in comparison to the dissipative resistance reaction, and this again means a large amount of energy stored up in comparison to the energy dissipated. This stored up energy is returned to the gen-

erator in the case of ordinary circuits and propagated in the case of long lines. The consideration of the angle of lag θ or, what is the same thing, *the power factor of the line*, enables us therefore to view the wave propagation in the same simple light in which we view the energy transfer in ordinary alternating current circuits. But it should be observed that *the power factor of the line* is not the same thing as the power factor of an ordinary alternating current circuit In wave propagation of electrical energy, the power factor of the line measures the power consumed on the line only; the power absorbed in the receiving apparatus is measured by another power factor.

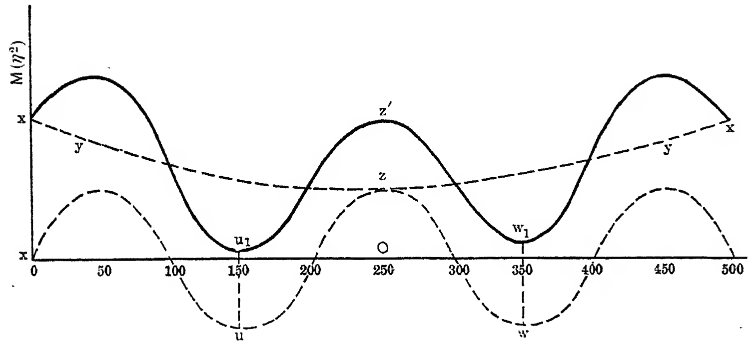


FIG. 2.

The mean square curves, equation (13) :—Plotting the curves by taking these mean squares for ordinates and ξ for the abscissa we obtain an extremely simple representation of the variation of the mean electro-kinetic energy during its propagation along the line. The thick line $x\ u_1\ z'\ w^1\ x$ diagram Fig. 2 represents the curve of $M\ (\eta^2)$. It consists of the superposition of two curves, the catenary $x\ y\ z\ y\ x$ and the simple harmonic $x\ u\ z\ w$. The wave-length of this simple harmonic is one-half as long as the wave-length of the progressive wave, that is

$$u\ w = \frac{\lambda}{2}$$

Let $u_1\ w_1$ be two points on the $M\ (\eta^2)$ curve such that $u\ w = u_1\ w_1$, then these points will be shown to be important points in the experimental determination of the wave-length.

Concerning an experimental method of measuring the wave-length and the velocity of propagation of long electrical waves: —Many serious attempts were made long before the time of Hertz to measure the velocity of propagation of an electrical

disturbance in a linear conductor. The most notable among these were the experiments of Wallaston and Fizeau. The cause of their failure has been discussed before, and needs no further commentary here. Hertz was the first to conceive the idea of determining this velocity by measuring experimentally the wave-length of a harmonic disturbance of known periodicity, and in order to obtain a sufficiently short wave-length he made the period sufficiently short. The solution of the problem of producing powerful harmonic electrical oscillations of very high frequency and therefore short wave-length forms the foundation of his classical experiments.

It will be pointed out now that the Hertzian method of measuring the velocity of propagation is applicable to forced electrical oscillations of long period; the difficulties involved in it will be brought out and a way of avoiding them will be discussed more fully in Section III. of this paper.

Consider as an illustration the following example:

$$l = 250 \text{ miles},$$
$$L = .005 \text{ henry},$$
$$R = 1 \text{ ohm},$$
$$C = .01 \text{ microfarad},$$
$$p = 6000.$$

Such a line represents very nearly a long-distance telephone line of 500 miles in length such as in use now between New York and Chicago. Fig. 2 is a $M(\eta^2)$ curve answering this example.

In this case we have approximately

$$\beta = .000706$$
$$v = 1.42 \times 10^5 \text{ miles, roughly.}$$
$$\frac{\lambda}{2} = 142 \text{ miles,} \qquad \text{"}$$

Hence

$$z\,w_1 = z\,u_1 = 71 \text{ miles}$$

At w_1 we have $\xi = 71$, hence

$$e^{2\beta\xi} = e^{142 \times .000706} = e^{\cdot 1}$$

This shows that the catenary is very flat in the vicinity of the origin o, the most distant point on the loop, and therefore the points u_1 and w_1 will be very near the minima points nearest to o. The distance between the minima is, therefore, equal to a

half wave-length corresponding to frequency 500. Hence if we plot the M (η^2) curve for a telephone line such as specified above, and determine the distance between the two furthest minima, this will give the half wave-length. Since the period is known, the velocity can be calculated. This method of determining experimentally the velocity of propagation is the same as the one devised by Hertz. It is evident, however, that in its practical execution it would offer many almost insurmountable difficulties, the chief among them being the excessively long wave-length and the consequent necessity of distributing the points of observation over long distances. But a simple consideration will show that a long period does not necessarily mean a long wave-length in the case of propagation along conductors. We have in this case

$$\lambda = T v = \frac{T}{\sqrt{L\,C}}$$

For a frequency of

$$T = \frac{1}{500}$$

we have

$$\lambda = 284$$

miles approximately.

If the surrounding medium had a million times the permeability and specific inductive capacity as the ordinary atmosphere we should have for the same conductor

$$\lambda = 1.5 \text{ foot, about,}$$

that is about the same wave-length as Hertz obtained for his very high frequencies. The velocity of propagation is a matter of the amount of energy per unit length of the path of the wave when a given current and potential are propagated along that path. We can make that amount anything we please, and thus modify the velocity of propagation and the wave-length in any desirable manner as will be shown in Sect. III.

Third case. The impedances of both the receiving and the transmitting apparatus are taken into account:—This is the most general case. Solution (6) in its complete form must be employed here. The current is the real part of

$$y = (2\,m \cos m\,\xi + h_1 \sin m\,\xi)\,\frac{D_0\,e^{ip}}{F}$$

The separation of the real and imaginary parts of this expression can be done as follows:—

$$\frac{D_0\, e^{ipt}}{F} = i\, A\, e^{i(pt-\psi)}$$

It can be shown that

$$2\, m \cos m\,\xi + h_0 \sin m\,\xi = X e^{\beta\xi} \cos(\alpha\xi + \varepsilon) + Y e^{-\beta\xi} \cos(\alpha\,\xi - \delta)$$

$$- i\,[X\, e^{\beta\xi} \sin(\alpha\xi + \varepsilon) - Y e^{-\beta\xi} \sin(\alpha\,\xi - \delta)\,]$$

Hence the real part of y will be

$$\eta = -A[X e^{\beta\xi} \cos(pt - \psi - \varepsilon - \alpha\xi) + Y e^{-\beta\xi} \cos(p\,t - \psi - \delta + \alpha\,\xi)\,] \quad (15)$$

The potential V is easily obtained from

$$\frac{\delta\,\eta}{\delta\,\xi} = C\,\frac{d\,V}{dt}$$

$$V = A_1[-X e^{\beta\xi} \sin(pt - \psi - \varphi - \varepsilon - \alpha\,\xi) + Y e^{-\beta\xi} \sin(p\,t - \psi - \varphi - \delta + \alpha\,\xi)\,] \quad (16)$$

$$V' = -V,\ A_1 = \frac{A\,\sqrt{\alpha^2 + \beta^2}}{p\,C}$$

$$\frac{\delta\,V}{\delta\,\xi} = A_1\,\sqrt{\alpha^2 + \beta^2}[X e^{\beta\xi} \cos(p\,t - \psi - \varepsilon - \alpha\,\xi + \theta) +$$

$$+ Y e^{-\beta\xi} \cos(p\,t - \psi - \delta + \alpha\,\xi + \theta)] \quad (16\ a)$$

where

$$\theta = \frac{\pi}{2} - 2\,\varphi$$

We have here as in the preceding case

$$\tan\,\varphi = \frac{\alpha}{\beta}\ \therefore\ \tan\,\theta = \frac{p\,L}{R}$$

where, as before, θ is the angle of lag between the potential gradient and the current, and *cos θ is the power factor of the line.*

$$\left.\begin{aligned} M(\eta^2) &= \frac{A^2}{2}[X^2 e^{2\beta\xi} + Y^2 e^{-2\beta\xi} + 2XY\cos(2\alpha\xi - \varepsilon + \delta)] \\ M(V^2) &= \frac{A_1^2}{2}[X^2 e^{2\beta\xi} + Y^2 e^{-2\beta} \;-2XY\cos(2\alpha\xi + \varepsilon - \delta)] \end{aligned}\right\} \quad (17)$$

The quantities A, A_1 X, Y, ε, δ can be calculated when required. The calculation is excessively long and tedious, and has been omitted on that account. The questions proposed in this investigation can be answered without a knowledge of the numerical values of these quantities.

Physical interpretation of the third case:—Little can be said here which has not already been mentioned in connection with the preceding case. *The current* and *the potential waves* are interference waves. The interfering components are two in number, just as in the preceding case.

$$\eta = \eta_1 + \eta_2$$

where

$$\eta_1 = -A\ Y\ e^{-\beta\xi}\cos(p\,t - \psi - \delta + \alpha\xi)$$

$$\eta_2 = +A\ X\ e^{\beta\xi}\cos(p\,t - \psi - \varepsilon - \alpha\,\xi + \pi)$$

η_1 is maximum at $\xi = -l$ and minimum at $\xi = 0$

η_2 " " " $\xi = 0$ " " " $\xi = -l$

Hence η_1 is the direct or the incident wave proceeding from the machine at the transmitting end, and η_2 is a reflected wave, the reflection taking place at the apparatus of the receiving end. In this respect, then, this case differs from the preceding one, there being no reflection when there is no receiving apparatus. The presence of the receiving apparatus acts as a source of secondary radiation. The reflected waves coming from the receiving apparatus may be called the counter-current waves produced by the counter-electromotive force due to the reaction at the receiving end. The transmitting apparatus acts like a source of light, and the receiving apparatus acts like a reflecting surface. But here is a distinction which deserves to be mentioned in this place. Light waves proceed in straight lines, whereas these electric waves bend around corners with perfect ease; they follow

the conducting wire. This difference is due principally to the fact that the current waves discussed here are conduction current waves, whereas the waves of light are waves of displacement currents of very short wave-length, and such waves will not bend easily around corners. Displacement current waves impinging upon a conductor will, of course, produce conduction currents and hence cross-talk in telephony, and there is every reason to believe that even ordinary light-waves when falling upon a conductor produce conduction current-waves which will bend around corners, if by the time they have reached a corner they have not been attenuated out of existence.

Comparing the potential gradient wave (16 a) to the current-wave it will be seen that the same angle of lag θ between the electromotive intensity or potential gradient and the current appears. It measures here in the same way as it did in the preceding case, the efficiency of transmission and on account of the same physical reasons. A line possessing perfect efficiency is like a perfectly transparent medium In such a medium the electric force and the magnetic are, at every point of a luminous wave, in quadrature.

The importance of this angle of lag can be shown here by inquiring how much energy per second passes at any point $-\xi$ toward the receiving apparatus.

Let $\frac{W}{2}$ = total power of transmitting apparatus radiated on one-half of the loop.

H = rate of heat generated on the line between the points $-l$ and $-\xi$.

It can be easily shown that

$$\frac{W}{2}=\frac{A\ A_1}{2}[(Y^2e^{2\beta l}-X^2e^{-2\beta l})\sin\varphi+2\,X\,Y\sin(\alpha l+\varepsilon-\delta)\cos\varphi]$$

$$H=\frac{W}{2}-\frac{AA_1}{2}[(Y^2e^{2\beta\xi}-X^2e^{-2\beta\xi})\sin\varphi+2XY\sin(\alpha\xi+\varepsilon-\delta)\cos\varphi]$$

The energy per second radiating from any point $-\xi$ toward the receiving apparatus is

$$\frac{W}{2}-H=E=\frac{AA_1}{2}[(Y^2e^{2\beta\xi}-X^2e^{-\beta\xi})\sin\varphi+2XY\sin(\alpha\xi+\varepsilon-\delta)\cos\varphi]$$

$$=E_1\sin\varphi-E_2\cos\varphi$$

Where E_1 and E_2 are positive quantities. Hence the greater φ the greater will be E.

Passing now to the consideration of the mean square values of η and V we obtain additional illustrations of the physical fact that long-distance transmission of power along conducting wires is a process of transference by means of wave radiation following the same laws as every other kind of wave radiation. Equations (17) express simply a geometrical relation between the incident and the reflected waves of current and potential, and their resultants. They state that these resultants are found by the ordinary rules of compounding waves or vectors in general. Now it happens, fortunately, that the mathematical expression for these resultants admits of a very simple geometrical construction, and of a suggestive mechanical illustration.

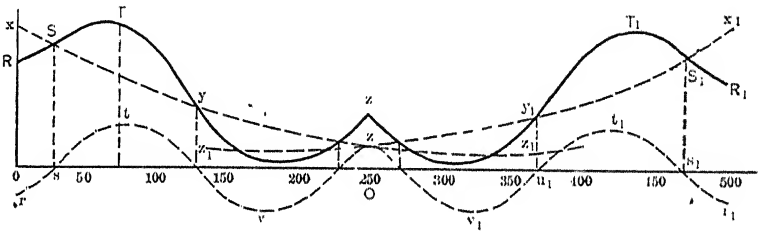


FIG. 3.

In Fig. 3 the thick line $R\ S\ T\ Z\ T_1\ S_1\ R_1$ represents the $M(\eta^2)$ curve on a 500-mile telephone line mentioned above. Each half consists of the superposition of a simple harmonic $r\ t\ u\ v\ z$ upon a portion of a catenary $x\ S\ y\ z$. It should be observed that the lowest point of the catenary of which $x\ S\ y\ z$ is a portion is to the right of z. That is to say, the double catenary $x\ S\ y\ z\ y_1\ s_1\ x_1$ is the catenary which we obtain by hanging a weight at the middle point of a heavy string which is suspended at its terminals. So that the effect of the receiving apparatus upon the $M(\eta^2)$ curve may be described broadly by stating that this curve can be represented by the forced vibrations of a heavy string, the extremities of which are held by a certain tension at two points on the same horizontal line and carrying a weight at its middle point. The density of the string, the stretching tension, and the weight at its middle point, correspond to the coefficient of self induction and the capacity per unit length of the wire, and to the self-induction of the receiving apparatus, respectively.

An interesting analogy will be mentioned here. If the self-induction of the receiving apparatus is balanced by a capacity,

and the resistance is negligibly small, the cusp of Fig. 3 disappears and in place of it we have the same formation as in Fig. 2. This case corresponds to a weight suspended by means of a spiral spring to the middle of the string, the weight and the elasticity of the spring being adjusted so that their period equals the period of the impressed force.

Note.—Another way of looking upon the effect of the line reactance upon the efficiency of transmission is to consider the attenuation constant β. When the reactance per unit length of line is large in comparison to resistance then for all frequencies

$$\beta = \tfrac{1}{2} R\, C\, v,$$

where v is the velocity of propagation and it is given by

$$v = \frac{1}{\sqrt{L C}}$$

This relation takes place here of the so-called $K R$ law.

The reactance diminishes the speed of propagation, but enables the line to transmit all frequencies (within certain limits which are of importance in telephony) with the same velocity and the same attenuation. It makes the line what Mr. Heaviside calls " distortionless."

FREE OSCILLATIONS ON A LINEAR CONDUCTOR OF UNIFORMLY DISTRIBUTED SELF-INDUCTION, RESISTANCE, AND CAPACITY.

§ 2. Free oscillations on a conductor of this kind are readily calculated for a few special cases. Equation (6) is a general solution for free oscillations also, provided, however, that m has such a value as to make

$$F = 0, \text{ since } D_0 = 0$$

that is, we must have

$$(h_0\, h_1 - 4\, m^2) \sin m\, l + 2\, m\, (h_0 + h_1) \cos m\, l = 0 \qquad (19)$$

but, of course, in this case

$$\begin{aligned} h_0 &= k\ C\ (k\, \lambda_0 + R_0) \\ h_1 &= k\ C\ (k\, \lambda_1 + R_1) \\ -m^2 &= k\ C\, (k\, L + R) \end{aligned}$$

Equation (19) is a transcendental equation and can be be solved in a few simple cases.

Case 1. *The transmitting and the receiving apparatus are not present.*

In this case

$$h_0 = h_1 = 0$$

Equation (19) reduces to

$$\sin m\, l = 0$$

$$\therefore m = \frac{s\,\pi}{l}$$

where s can have any integer value from 1 to ∞. The periods of free oscillations are calculated from the equation

$$-m^2 = k^2 L\, C + k\, R\, C = -\frac{s^2\,\pi^2}{l^2}$$

$$\therefore k = -\frac{R}{2\,L} \pm \sqrt{-1}\sqrt{\frac{1}{L\,C}\frac{s^2\,\pi^2}{l^2} - \frac{R^2}{4\,L^2}}$$

$$= -\frac{R}{2\,L} \pm i\, k_s$$

There are therefore an infinite number of periods which are harmonically related to each other unless the damping factor $\frac{R}{2\,L}$ is not sufficiently small in comparison to $\frac{\pi^2}{l^2}\frac{1}{LC}$.

The most general solution of this case can be written

$$y = e^{-\frac{R}{2L}t}\, {}^{s}\!\sum_{1}^{\infty} A_s \cos\frac{s_l\pi}{l}\xi \cos(k_s\, t - \varepsilon_s) \tag{20}$$

Case 2.—Transmitting apparatus is not present and in place of the receiving apparatus there is a break in the wire.

In this case $h_0 = o$, $h_1 = \infty$

Equation (19) reduces to

$$\cos m\, l = 0$$

$$\therefore m = \frac{2\,s + 1}{l}\,\frac{\pi}{2}$$

$$k = -\frac{R}{2L} \pm i\sqrt{\frac{1}{L\,C}\left(\frac{2\,s + 1}{l}\;\frac{\pi}{2}\right)^2 - \frac{R^2}{4L^2}}$$

$$= -\frac{R}{2\,L} \pm i\, k_{2s+1}$$

$$y = e^{-\frac{Rt}{2L}}\; {}^{s}\!\sum_{0}^{\infty} A_{2s+1} \sin\frac{2\,s + 1}{l}\,\frac{\pi}{2}\cos(k_{2s+1} - \varepsilon_{2s+1}) \tag{21}$$

The damping factor is the same for all frequencies, hence the color of the complex harmonic vibration remains unchanged during the whole epoch while the vibrations last. The dying out sound of a bell is a striking illustration of this interesting relation.

Whenever the circuit is made or opened, we shall have in addition to the forced vibrations, free vibrations also. The lower harmonics of these free vibrations will be quite within the ordinary frequencies, especially on long lines. There is no doubt

that these free vibrations interfered considerably with the successful working of harmonic telegraphy. The discussion of a method of preventing the development of free vibrations of any period is reserved for a future occasion.

SECTION II.[1]

Oscillations on a Loaded Conductor.

Introduction:—This part of the paper discusses the forced and the free electrical oscillations in a loaded conductor.

First Arrangement.

The conductor consists of $2n$ equal coils, $L_1 \ldots . L_n$ (Fig. 4) connected in series, so as to form a closed loop. At one point A of this loop is an alternator, at the diametrically opposite point is a receiving apparatus B. At equal distances $(n - 1)$ equal condens-

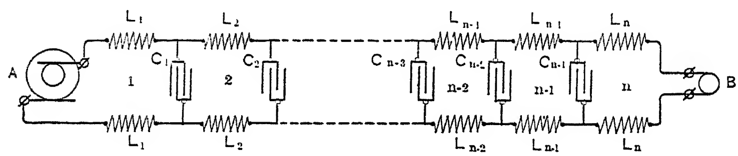


Fig. 4.

ers, $C_1 \ldots . C_{n-1}$, form bridges across the loop. The whole loop is thus divided into n component circuits, 1, 2....n. The component circuits except the first and the nth are equal to each other in the sense that they have equal resistance, capacity, and self-induction. The first and the nth circuit differ from the other circuits on account of the presence of alternator A in the former, and that of the receiving apparatus B in the latter circuit.

It is evident that in the limit when n becomes infinitely large, this conductor becomes an ordinary telegraph or telephone line with uniformly distributed resistance, capacity, and self-induction. The practical question arises now, under what conditions will a conductor loaded in this manner become equivalent with sufficient approximation to a uniform telegraph line when n is not infinitely large? This problem does not seem to have been solved before. Professor Blakesley in his book on alternating currents devotes considerable attention to the discussion of a similar problem, but his efforts do not appear to throw any light upon this matter.

1. This section read before the *American Mathematical Society*, March meeting, 1899.

In its main features this problem is similar to that which Lagrange solved in his "Mecanique Analytique, sec. partie, sect. VI.," the problem, namely, of the free vibrations of a string, fixed at its two ends, and loaded at equidistant points by equal weights. But it is much more general than that of Lagrange, in the first place because frictional resistances are taken into consideration, and secondly, forced as well as free oscillations are considered.

Specification of the constants and of the currents:—

Let L_0 and L_1 = co-efficient of self-induction of A and B respectively.

Let R_0 and R_1 = Ohmic resistance of A and B, respectively.

Let C_0 and C_1 = Capacity of A and B, respectively.

Let L, R, C, be the corresponding quantities of the coils and condensers in the several component circuits.

Let the real part of $E e^{ipt}$ be the E.M.F. impressed by the alternator A.

Let $x_1 \ldots . x_n$ be the currents in the n component circuits.

Let $P_1 \ldots . P_{n-1}$ be the differences of potential in the line condensers.

Let P_0 and P' be the differences of potential in the condensers in A and B, respectively.

Let $\xi_1 \ldots . \xi_{n-1}$ be the condenser currents.

We shall have

$$\left.\begin{aligned} \xi_1 &= C\frac{dP_1}{dt}, \qquad \xi_2 = C\frac{dP_2}{dt}, \text{ etc.} \\ \xi_1 &= x_1 - x_2, \qquad \xi_2 = x_2 - x_3, \text{ etc.} \end{aligned}\right\} \tag{1}$$

A. Forced Oscillations.

Stating the law of equality of action and reaction for each component circuit we obtain the following n differential equations:—

$$\left.\begin{aligned} (L_0 + 2\,L)\frac{dx_1}{dt} + (R_0 + 2\,R)\,x_1 + P_1 + P_0 &= E\,e^{ipt} \\ 2\,L\frac{dx_2}{dt} + 2\,R\,x_2 + P_2 - P_1 &= 0, \\ \cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots \\ 2\,L\frac{dx_{n-1}}{dt} + 2\,R\,x_{n-1} + P_{n-1} - P_{n-2} &= 0, \\ (L_1 + 2\,L)\frac{dx_n}{dt} + (R_1 + 2\,R)\,x_n - P_{n-1} + P' &= 0. \end{aligned}\right\} \tag{2}$$

When the steady state has been reached, the currents will be just like the impressed E.M.F., simple harmonics of the time t, that is

$$
\begin{aligned}
x_1 &= A_1\, e^{ipt}, \\
x_2 &= A_2\, e^{ipt}, \qquad (3) \\
&\ldots\ldots\ldots\ldots
\end{aligned}
$$

where $A_1, A_2, \ldots$ are complex quantities.

From (3) follows that for the differential co-efficients in (2) we can substitute currents, because

$$
\left.
\begin{aligned}
\frac{d\,x_m}{dt} &= i\,p\,x_m \\
\frac{d^2\,x_m}{dt^2} &= -\,p^2\,x_m
\end{aligned}
\right\} \qquad (4)
$$

Hence differentiating each member of (2) and substituting from (4) and (1) we obtain

$$
\begin{aligned}
&2\,C(-p^2\,L + i p\,R)\,x_1 \;+ \xi_1 \;- 0 \quad = i p\,C\,E\,e^{ipt} \\
&\qquad\qquad\qquad\qquad\qquad\qquad + C(p^2\,\lambda_0 - i p\,R_0)\,x_1 \\
&2\,C(-p^2\,L + i p\,R)\,x_2 \;+ \xi_2 \;- \xi_1 \quad = 0 \\
&\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \\
&2\,C(-p^2\,L + i p\,R)\,x_{n-1} + \xi_{n-1} - \xi_{n-2} = 0 \\
&2\,C(-p^2\,L + i p\,R)\,x_n \;+ 0 \;- \xi_{n-1} = C\,(p^2\,\lambda_1 - i\,p\,R_1)\,x_n
\end{aligned}
$$

where

$$
\lambda_0 = L_0 - \frac{1}{p^2\,C_0}\,, \quad \lambda_1 = L_1 - \frac{1}{p^2\,C_1}
$$

Introducing the following abbreviations:—

$$
\begin{aligned}
h &= 2\,C\,(-\,p^2\,L + i\,p\,R\,) \\
D &= i\,p\,C\,E\,e^{ipt} + C\,(p^2\,\lambda_0 - i\,p\,R_0) = D_0 - h_0\,x_1 \\
h_1 &= -\,p^2\,\lambda_1 + i\,p\,R_1
\end{aligned}
$$

we obtain

$$
\left.
\begin{aligned}
&h\,x_1 \;\; + \xi_1 \;\; - 0 \quad = D \\
&h\,x_2 \;\; + \xi_2 \;\; - \xi_1 \quad = 0 \\
&\ldots\ldots\ldots\ldots\ldots\ldots\ldots \\
&h\,x_{n-1} + \xi_{n-1} - \xi_{n-2} = 0 \\
&h\,x_n \;\; + 0 \;\; - \xi_{n-1} = -\,h_1\,x_n
\end{aligned}
\right\} \qquad (5)
$$

Another form is obtained by substituting for ξ_1 ξ_2 .. as follows:—

$$\left.\begin{array}{l}(h_0 + h + 1)\,x_1 \;\; + 0 \;\; - x_2 \;\; = D_0 \\ \qquad (h + 2)\,x_2 \;\; - x_1 \;\; - x_3 \;\; = 0 \\ \cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots \\ \qquad (h + 2)\,x_{n-1} - x_{n-2} - x_n \;\; = 0 \\ (h_1 + h + 1)\,x_n \;\; + 0 \;\; - x_{n-1} = 0\end{array}\right\} \quad (6)$$

Two methods of solving these equations present themselves, the direct method and the indirect one.

The direct method:—In this method the system (6) forms the starting point. Consider the following determinant:—

$$\begin{vmatrix} h_0+h+1, & -1, & 0, & 0, & \cdots & & & \\ -1, & (h+2), & -1, & 0, & \cdots & & & \\ 0, & -1, & h+2, & -1, & 0 \cdots & & & \\ \cdots & & & & & & & \\ 0, & 0, & 0, & 0, & 0, \cdots & -1, & h+2, & -1 \\ 0, & 0, & 0, & 0, & 0, \cdots & 0, & -1, & (h_1+h+1) \end{vmatrix} = \Delta$$

Let now Δ_m stand for the minor of that term in the *m*th column which contains h, then

$$x_m = \frac{\Delta_m}{\Delta} D_0 \qquad (7)$$

If Δ_m and Δ could be evaluated by the ordinary rules of expanding a determinant then (7) would give the solution of the problem for forced oscillations. The free oscillations could then be readily obtained from it. But the direct expansion of Δ_m and Δ seems to be a matter of much difficulty, so that (7) is merely a symbolic solution of no actual value. The direct method leads, therefore, to no effective result. In his investigation of the problem referred to above, Lagrange did not adopt the direct method. The indirect method employed in this paper is different from that employed by him, and it had to be devised as Lagrange's method does not seem to be applicable here, because, as already stated, the two problems, though similar in their general features, are essentially different.

The indirect method:—This method may be called the method of successive eliminations.

The starting point is system (5). Adding the n equations we obtain

$$h\,(x_1 + x_2 + \ldots + x_{n-1} + x_n) = D - h_1\,x_n \qquad (8)$$

The indirect method can now be readily explained. It consists in successively eliminating from the left-hand member of (8) the currents $x_n \ldots x_2$ and thus obtaining in place of (8) an equation containing in its left-hand member x_1 as the only unknown quantity. From this equation the complete solution of the problem can then be easily obtained.

Elimination of x_n.

First step.

$$\begin{aligned}
x_1 &= x_1 \\
x_2 &= x_1 - \xi_1 \\
x_3 &= x_1 - \xi_1 - \xi_2 \\
x_4 &= x_1 - \xi_1 - \xi_2 - \xi_3 \\
&\ldots\ldots\ldots\ldots \\
x_{n-1} &= x_1 - \xi_1 - \xi_2 - \xi_3 - \ldots - \xi_{n-3} - \xi_{n-2} \\
x_n &= x_1 - \xi_1 - \xi_2 - \xi_3 - \ldots - \xi_{n-3} - \xi_{n-2} - \xi_{n-1}
\end{aligned}$$

$$\therefore h\,(x_1 + \ldots + x_n) = n\,h\,x_1 - h\,[\,(n-1)\,\xi_1 + (n-2)\,\xi_2 + \ldots + 2\,\xi_{n-2} + \xi_{n-1}] \qquad (9)$$

Second step.

$$\begin{aligned}
\xi_1 &= D - h\,x_1 \\
\xi_2 &= D - h\,(x_1 + x_2) \\
\xi_3 &= D - h\,(x_1 + x_2 + x_3) \\
&\ldots\ldots\ldots\ldots \\
\xi_{n-1} &= D - h\,(x_1 + x_2 + \ldots + x_{n-1})
\end{aligned}$$

$$\therefore (n-1)\,\xi_1 + (n-2)\,\xi_2 + \ldots + 2\,\xi_{n-2} + \xi_{n-1} = \frac{n\,(n-1)}{2}\,D - \frac{h}{2}\,[n\,(n-1)\,x_1 + (n-1)\,(n-2)\,x_2 + \ldots] \qquad (10)$$

By means of (9) and (10) equation (8) transforms into

$$n\,h\,x_1+\frac{h^2}{2}[n(n-1)x_1+(n-1)(n-2)x_2+\ldots\ldots+2\times1\,x_{n-2}+x_{n-1}]$$

$$=D\,[1+\frac{n\,(n-1)}{2}\,h]-h_1\,x_n \quad (11)$$

In place of (8) we have (11) and in the left-hand member of this equation, x_n does not appear.

To eliminate the remaining variables $x_{n-1},\ldots.x_2$ we have to repeat the same operations through which we have just passed during the elimination of x_n. In each elimination the same two steps just shown have to be made. It seems, therefore, superfluous to go into any further details here. Before giving the final result it is well to observe here, that the following theorem can be employed with advantage in performing the summations which occur in each elimination.

Theorem :—

Let $S=1.2.3\ldots\ldots\ldots(s+1)+2.3\ldots\ldots\ldots(s+2)+\ldots\ldots\ldots$

$$+\,(n-s)\,(n-s+1)\ldots\ldots\ldots n,$$

then

$$S=\frac{(n-s)\,(n-s+1)\ldots\ldots\ldots n\,(n+1)}{s+2}$$

It can be proved as follows:

$$(n-s)\,(n-s+1)\ldots\ldots\ldots n=\frac{1}{s+2}\,[(n-s)\ldots\ldots\ldots n\,(n+1)$$

$$-(n-s-1)\ldots\ldots\ldots n]=\frac{1}{s+2}\,[\,U_{n-s}-U_{n-s-1}\,]$$

It is evident that

$$S=\frac{1}{s+2}\,[\,U_{n-s}-U_{n-s-1}+U_{n-s-1}-U_{n-s-2}$$

$$+\ldots.+U_2-U_1+U_1-U_0\,]=\frac{1}{s+2}\,U_{n-s}$$

since $$U_0=0$$

The final result of the eliminations indicated above is

$$x_1 [n\,h + \frac{(n+1)\,n\,(n-1)}{3\,!} h^2 + \frac{(n+2)(n+1)\,n\,(n-1)(n-2)}{5\,!} h^3 + \,.\,.\,] =$$

$$= D\,[1 + \frac{n\,(n-1)}{2\,!} h + \frac{(n+1)\,n\,(n-1)\,(n-2)}{4\,!} h^2 + \ldots .]$$

$$- h_1\, x_n \ldots . \quad (12)$$

Equation (12) takes place of equation (8). Its left-hand member contains the variable x_1 only. The ultimate object of the successive eliminations has, therefore, been reached. Our problem now can be readily solved. The last equation can be much simplified by the following substitution:

$$h = -4 \sin^2 \theta$$

Consider the mth term of the left-hand member of (12), namely:

$$x_1 \frac{(n+m-1)\;(n+m-2)\;\ldots .\; n\; \ldots .\;(n-m+2)\;(n-m+1)}{(2\,m-1)\,!} h^m$$

This term becomes

$$\frac{x_1\,(-1)^m\,[(2\,n)^2 - 2^2\,(m-1)^2]\;[(2\,n)^2 - 2^2\;(m-2)^2]\ldots .2\,n}{(2\,m-1)\,!}$$

$$\times\; 2 \sin \theta \sin^{2\,m-1} \theta$$

or if we put $2\,n = \nu$, then the left-hand member of (12) becomes

$$-x_1\, \nu \sin \theta\, [\sin \theta - \frac{\nu^2 - 2^2}{3\,!} \sin^3 \theta + \frac{(\nu^2 - 2^2)\,(\nu^2 - 4^2)}{5\,!} \sin^5 \theta - \ldots ..]$$

The series in parenthesis is well known.[1] The expression can be written in the following concise form:

$$-\frac{2 \sin \theta \sin 2\,n\,\theta}{\cos \theta} x_1$$

It may be shown now in a similar manner that the right-hand member of (12) can be written

$$\frac{D \cos (2\,n - 1)\,\theta}{\cos \theta} - h_1\, x_n$$

1. Todhunter Trigonometry, p. 230.

Equation (12) can, therefore, be written

$$x_1 = \frac{-D\cos(2n-1)\theta + h_1 x_n \cos\theta}{2\sin\theta\sin n\theta} \quad \ldots .(13)$$

The remaining currents can now be easily calculated. Thus

$$\begin{aligned} x_2 &= (h+1)x_1 - D \\ &= (2\cos 2\theta - 1)x_1 - D \\ &= \frac{h_1 x_n \cos 3\theta - D\cos(2n-3)\theta}{2\sin\theta\sin 2n\theta} \\ x_3 &= \frac{h_1 x_n \cos 5\theta - D\cos(2n-5)\theta}{2\sin\theta\sin 2n\theta} \end{aligned}$$

It is evident that in general

$$x_m = \frac{h_1 x_n \cos(2m-1)\theta - D\cos[2(n-m)+1]\theta}{2\sin\theta\sin 2n\theta} \quad (14)$$

This expression for x_m is still incomplete as it contains two unknown quantities, namely x_n and x_1. The last one is contained in $D = D_0 - h_0 x_1$. These two have now to be eliminated.

Let $m = n$, then

$$x_n = \frac{h_1 x_n \cos(2n-1)\theta - (D_0 - h_0 x_1)\cos\theta}{2\sin\theta\sin 2n\theta}$$

From which

$$\begin{aligned} x_n &= \frac{(D_0 - h_0 x_1)\cos\theta}{h_1\cos(2n-1)\theta - 2\sin\theta\sin 2n\theta} \\ &= \frac{(D_0 - h_0 x_1)\cos\theta}{(h_1 - 1)\cos(2n-1)\theta + \cos(2n+1)\theta} \\ &= \frac{(D_0 - h_0 x_1)\cos\theta}{A} \quad \ldots . \end{aligned} \quad (15)$$

From (14) we obtain by substituting $D_0 - h_0 x_1$ for D the following value for x_1

$$\begin{aligned} x_1 &= \frac{D_0\cos(2n-1)\theta - h_1 x_n \cos\theta}{(h_0 - 1)\cos(2n-1)\theta + \cos(2n+1)\theta} \\ &= \frac{D_0\cos(2n-1)\theta - h_1 x_n\cos\theta}{B} \end{aligned} \quad (16)$$

Combining (15) and (16) we obtain

$$x_1 = \frac{[A \cos (2n - 1)\theta - h_1 \cos \theta] D_0}{A B - h_1 h_0 \cos^2 \theta}$$

$$x_n = - \frac{D_0 \sin 2\theta \sin 2n\theta}{A B - h_0 h_1 \cos^2 \theta}$$

The most convenient way of finding the value of any c current, say x_m, is to go back to (6) and find x_2 from the equation by inserting the value of x_1 from (17). We find

$$x_2 = \frac{[A \cos (2n - 3)\theta - h_1 \cos \theta \cos 3\theta] D_0}{A B - h_0 h_1 \cos^2 \theta}$$

The general formula can now be easily guessed. It is

$$\left.\begin{aligned} x_m &= \frac{[A \cos (2n-2m+1)\theta - h_1 \cos \theta \cos (2m-1)\theta] D_0}{A B - h_0 h_1 \cos^2 \theta.} \\ &= \frac{[2\sin\theta\cos(2n-2m+1)\theta + h_1\sin(2n-2m+2)\theta] D_0}{h_0 h_1 \sin(2n-2)\theta - 4\sin^2\theta\sin 2n\theta + 2\sin\theta(h_0+h_1)\cos(2n-1)\theta} \end{aligned}\right\}$$

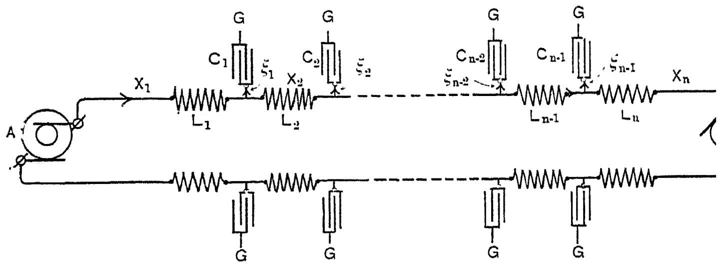


Fig. 5.

This value of x_m satisfies all the conditions, which forced lations have to satisfy. It is therefore the complete soluti our problem for forced oscillations, taking into account tl actions of the transmitting and the receiving apparatus. angle θ is a complex angle, so that the real part of (19) i actual current in circuit m.

Second Arrangement.

In this arrangement there are 2 $(n-1)$ condensers ea capacity C, all connected to ground as shown in Fig 5. In of (5) and (6) we shall have here the following differ equations :—

$$\left.\begin{array}{l} h\,x_1 + \xi_1 - 0 \quad = \frac{1}{2}\,(D_0 - h_0\,x_1) \\ h\,x_2 + \xi_2 - \xi_1 \quad = 0 \\ \dots\dots\dots\dots\dots\dots\dots\dots \\ h\,x_m + \xi_m - \xi_{m-1} = 0 \\ \dots\dots\dots\dots\dots\dots\dots\dots \\ h\,x_n + 0 \quad - \xi_{n-1} = -\frac{1}{2}\,h_1\,x_n \end{array}\right\} \quad (20)$$

or

$$\left.\begin{array}{l} (h+1)\,x_1 - 0 \quad - x_2 \quad = \frac{1}{2}\,(D_0 - h_0\,x_1) \\ (h+2)\,x_2 - x_1 \quad - x_3 \quad = 0 \\ \dots\dots\dots\dots\dots\dots\dots\dots \\ (h+2)\,x_m - x_{m-1} - x_{m+1} = 0 \\ (h+1)\,x_n - x_{n-1} - 0 \quad = -\frac{1}{2}\,h_1\,x_n \end{array}\right\} \quad (21)$$

Solution (19) will therefore hold for these equations also, provided that in it we multiply h_0, h_1, and D_0 by $\frac{1}{2}$ and also remember that in this case

$$-4\sin^2\theta = (-p^2\,L\,C + i\,p\,R\,C) = h$$

Note:—Solution (19) can also be obtained by a short cut. Equation (6) of Section I. of this paper suggests the following as a trial solution:—

$$x_m = K_1\cos 2\,(n-m)\,\theta + K_2\sin 2\,(n-m)\,\theta.$$

It will be found that this satisfies all equations in (6) and (21) except the first and the last, provided that

$$h = -4\sin^2\theta.$$

Now by giving K_1 and K_2 their proper values the first and the last equation may also be satisfied. Having thus determined K_1 and K_2 we obtain (19). Considerable calculation can thus be saved. The longer and more tedious method was selected be-

cause it offers a convenient means of discussing certain cases of wave propagation, not considered in this paper, which cannot very well be attacked directly by the infinitesimal method. This matter is reserved for a future occasion.

B. Free Oscillations.

Equation (19) holds true for free as well as forced oscillations. But since in the case of free oscillations $D_0 = 0$ it follows that the denominator of (19) must vanish to prevent the vanishing of all the currents We shall have, therefore, in this case

$$h_0 h_1 \sin(2n-2)\theta - 4\sin^2\theta \sin 2n\theta + 2\sin\theta\,(h_0+h_1)\cos(2n-1)\theta = 0 \quad (22)$$

From this equation θ has to be determined. A solution can be obtained for a small number of problems. The two most important will be considered here.

First. The transmitting and the receiving apparatus are not present. In this case

$$h_0 = h_1 = 0,$$

$$x_m = B \cos(2n - 2m + 1)\,\theta \quad (23)$$

It is found from (22) that (23) is actually the solution of the differential equations (6) for $h_0 = h_1 = D_0 = 0$, provided that

$$\theta = \frac{s\pi}{2n}$$

where s may be any integer from 1 to 2 n.

Hence the most general solution will be

$$x_m = \sum_{s=1}^{2n} B_s \cos(2n - 2m + 1)\frac{s\pi}{2n} \quad (24)$$

But it should be observed now that x_m is a periodic function of the time, that is

$$x_m = A_m\, e^{pt}$$

Hence in (24) each amplitude B contains the time factor e^{pt} that is

$$B_s = A_s e^{p_s t}$$

The constant p_s which measures the period of the free oscillation is determined from the relation

$$h = -4 \sin^2\theta.$$

In the case of free oscillations

$$h = p^2 L C + p R C,^* \quad \theta = \frac{s\pi}{2n}$$

Hence

$$p_s^2 L C + p_s R C = -4 \sin^2 \frac{s\pi}{2n} \tag{25}$$

This enables us to determine p_s. Before solving this equation it is desirable to make the following substitution:

Let L', C', R' be the total co-efficient of self-induction, capacity, and resistance, respectively, of one-half of the conductor, then

$$L = \frac{L'}{n}^*$$

$$C = \frac{C'}{n}$$

$$R = \frac{R'}{C}$$

Let l denote the half-length of a uniform wire having λ, r, c, for co-efficient of self-induction, resistance and capacity per unit length, and let

$$l\lambda = L', \qquad l r = R', \qquad l c = C'$$

then

$$L = \frac{l\lambda}{n}, \qquad C = \frac{l c}{n}, \qquad R = \frac{l r}{n}.$$

* This will apply to second arrangement, Fig. 5, but not to the first arrangement. The calculation for first arrangement is slightly different and can be easily made.

From (23) we obtain

$$\frac{l^2}{n^2}\left(p_s^2 \lambda c + p_s r\right) = -4 \sin^2 \frac{s\pi}{2n}$$

$$\therefore p_s = -\frac{r}{2\lambda} \pm \sqrt{-1}\sqrt{\frac{1}{\lambda c}\frac{4n^2}{l^2}\sin^2\frac{s\pi}{2n} - \frac{r^2}{4\lambda^2}}$$

$$p_s = -\frac{r}{2\lambda} \pm i k_s$$

Equation (22) becomes now

$$x_m = e^{-\frac{rt}{2\lambda}} \sum_{s=1}^{2n} A_s \cos(2n-2m+1)\frac{s\pi}{2n}\cos(k_s t - \varepsilon_s) \qquad (26)$$

Second case:—The transmitting apparatus is not present, and in place of the receiving apparatus there is a break in the line at B.

In this case $h_0 = 0$, $h_1 = \infty$. Equation (19) gives

$$x_m = B \sin(2n - m + 2)\theta$$

provided that

$$\cos(2n-1)\theta = 0$$

$$\text{or } \theta = \frac{2s+1}{2n-1}\frac{\pi}{2}$$

We shall have, therefore,

$$p_{2s+1} = -\frac{r}{2\lambda} \pm i\sqrt{\frac{1}{\lambda c}\frac{4n^2}{l^2}\sin^2\frac{2s+1}{2n-1}\frac{\pi}{2} - \frac{r^2}{4\lambda^2}}$$

$$= -\frac{r}{2\lambda} \pm i k_{2s+1}$$

$$\therefore x_m = e^{-\frac{rt}{2\lambda}} \sum_{s=0}^{2n} A_{2s+1} \sin(2n-2m+2)\frac{2s+1}{\theta n-1}\frac{\pi}{2}\cos(k_{2s+1}t - \varepsilon_{2s+1}) \qquad (27)$$

The question arises now, under what conditions will a loaded conductor of this kind become approximately equivalent to a uniform wire?

Let

$$L = .0125$$
$$C = .025$$
$$R = 2.5$$
$$p = 3000$$

that is the frequency is about 500 $p.p.s.$

It will be found that since

$$-4 \sin^2 \theta = -p^2 L C + i p R C = -(\alpha + i \beta)^2 = -4 \mu^2$$

or

$$\sin \theta = \tfrac{1}{2}(\alpha + i \beta) = \mu$$
$$= .026 + .0014\, i$$
$$\theta = \mu \text{ very nearly.}$$

If n coils have the same co-efficient of self-induction, the same capacity and the same resistance as a uniform wire of length l, and m coils correspond to a length s, then

$$m : n :: s : l$$

$$\therefore m = \frac{ns}{l}$$

and

$$2(n-m)+1\ \theta = 2n\left(1 - \frac{s}{l} + \frac{1}{2n}\right)\mu$$

Again

$$-p^2 L C + i p R C = \frac{l^2}{n^2}(-p^2 \lambda c + i p r c) = -\frac{l^2}{n^2} m^2$$

where m has the same meaning as in section I.

$$\therefore \theta = \mu = \frac{l}{n}\frac{m}{2}$$

$$\therefore 2n\left(1 - \frac{s}{l} + \frac{1}{2n}\right)\mu = \left(l - s + \frac{l}{2n}\right)m$$
$$= (l - s)\, m$$

when n is large

In the apparatus described in Sect. III, $n = 200$ hence above expression reduces to

$$2n\left(1-\frac{s}{l}+\frac{1}{400}\right)\mu=(l-s)\,m=m\,\xi$$

When this value of θ is substituted in (19), this equation reduces to equation (6) of Section I., which shows that under the conditions just described, the loaded conductor described here becomes equivalent to a uniform wire. Experiments performed upon the loaded conductor described in Section III, verify this theoretical conclusion. Up to about 1000 p.p.s. the loaded conductor (having for L, C, R, of each section the values given above) behaves, very nearly, like a uniform slow-speed conductor.

SECTION III.

Experiments with Slow-Speed Conductors.

Slow-Speeed Conductor with uniformly distributed capacity, self-induction and resistance.—This conductor consists of a number of coils, generally twenty-four, joined in series. The construction of each coil is represented in Fig. 6. A number of

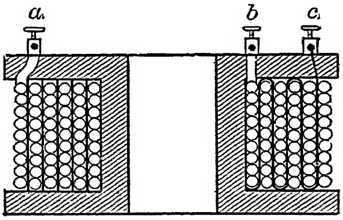


Fig. 6.

layers of No. 20 wire are wound upon a wooden spool; the height of the layers is three inches, the diameter of the inside layer is seven inches, the number of layers is eight. Each layer when wound is covered with a sheet of paraffined paper, then a sheet of tinfoil is wrapped and covered with a sheet of paraffined paper, and then the next layer is wound. The same operation is repeated after each layer of wire. The tinfoil sheets are all connected in series and to the binding post c. The thick vertical lines between the layers represent the tinfoil. The spools are carefully turned and everything is done to secure the equality of the coils. Experimental measurements of the electrical constants of the coils showed that the coils were equal to each other to

within less than one per cent. But it should be observed that this equality can be verified experimentally when the coils are well heated up so as to expel the moisture between the layers; moisture prevents an accurate measurement of capacity on account of excessive leakage. The heating was done electrically. By repeated trials the result aimed at was finally obtained, namely, that each coil should have the following constants:—

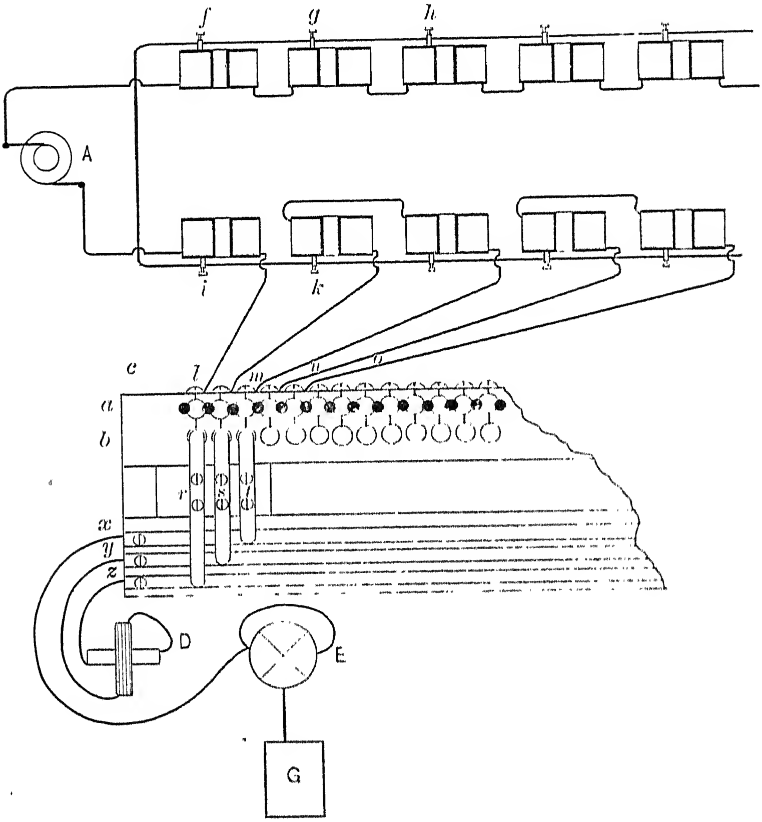


Fig. 7.

$$L = .05 \text{ henry}$$

$$C = .1 \text{ microfarad}$$

$$R = 10 \text{ ohms}.$$

That is to say, each coil was equivalent to about ten miles of telephone wire now in use between New York and Chicago. The leakage was more than on ordinary telegraph lines under fair conditions. It cannot be avoided in coils of this kind, but as long

as the impressed E.M.F. is not above 300 volts it does not interfere very seriously with the successful operation on conductors of this kind.

The coils were connected in series as represented in Figs. 7 and 7ª. In Fig. 7. the exciting machine is A. The binding posts *f g* to *i k* . . . lead to the tinfoils. They are all connected together and then grounded. The coils are not connected to each other directly but through a switchboard *a b x y z*, the lower part of Fig. 7. This switchboard is constructed as follows:—Into a well-seasoned board of oak X Y Z Fig. 7ª and *a b x y z* Fig. 7 are driven two rows of circular brass plugs *a*. . . *c* . . . Fig 7 or *b c d* . . . *h i k* . . . Fig. 7ª. These are connected by rods driven in from binding screws *s t u* . . Fig. 7ª. The upper row of plugs

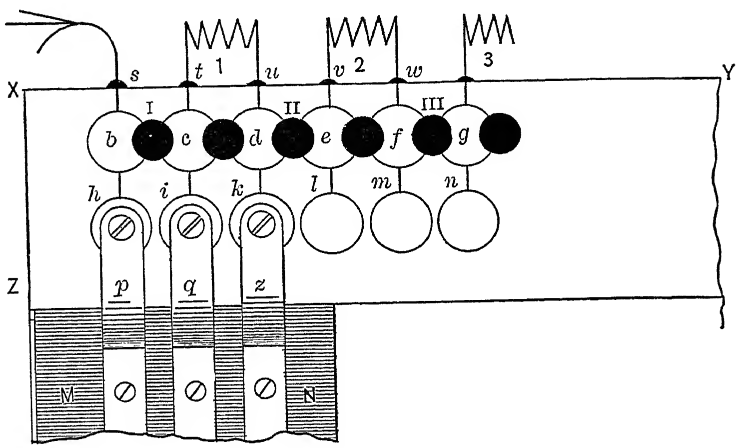


FIG. 7ª.

has holes I, II, III, represented by black circles in (Fig. 7ª) into which plungers, ordinary condenser plugs, are inserted; thus a plunger in I (Fig. 7ª) connects plugs *b* and *c*. The connection of the coils to the brass plugs is represented correctly in Fig. 7ª (but not in Fig. 7 owing to a mistake of the draughtsman). A wire *a* leads from alternator A to the first plug *b*. The terminals of the coils 1, 2, 3, etc., are connected as represented to binding screws *t*, *u*, *v*, *w*, . . . Suppose now that the connecting plungers are in I, II, III, etc., the coils are then connected together and the circuit is established. To measure the current and the potential at various points of this circuit proceed as follows:—Three long brass bars *x y z* (Fig. 7) running parallel to the rows of brass plugs can be connected to any three consecutive plugs by means of three brass

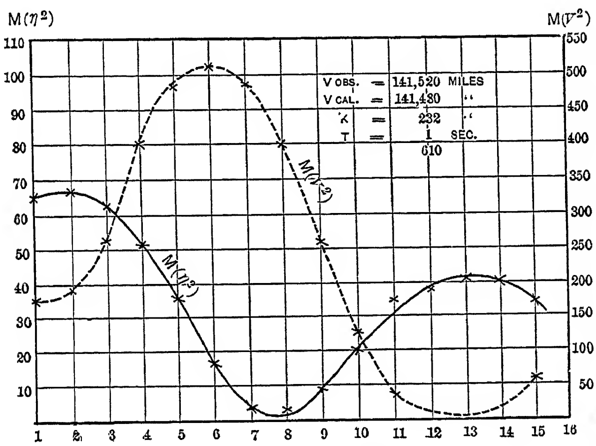
strips $z\ s\ t$ (Fig. 7) or $p\ q\ z$ (Fig. 7[a]). The two upper bars $x\ y$ Fig. 7 are connected to a Siemens electro-dynamometer D (reading down to .02 ampere), the lower is connected to a Thomson multicellular voltmeter E (reading up to 250 volts). Suppose now that a reading is to be taken at the point between coils 1 and 2. That would correspond to a point 10 miles outside of the sending station on the long-distance telephone wire mentioned above. The brass strips $p\ q\ z$ (Fig. 7[a]) which are connected to a wooden slide M N (Fig. 7[a]) are moved to the right until strip p reaches plug k; at the same time q will be on l and z will be on m. The connecting plunger in II is then removed and the current made to pass through the electro-dynamometer, D, at the same time the voltmeter E is connected to point III. The two readings give the mean square of current at II and the R.M.S. of potential at III. The readings from which curves in Fig. 8 and Fig. 9 were plotted were taken in this manner.

The alternators which supplied the impressed E.M.F. were two small machines, each having four separate armatures and four fields. The four fields rotated on the same shafts. In this manner any frequency between about 25 P.P.S. and 750 P.P.S. could be obtained. The E.M.F.'s generated were not simple harmonics; the effect of the higher harmonics (the fifth was predominant, but not strong) was weakened by tuning. Well known precautions were taken to keep the speed and excitation constant. The electromotive forces employed ranged between 60 and 234 volts. The length of the equivalent line operated upon was usually 240 miles. The number of observations made ran into hundreds. The two recorded in Fig. 8 and Fig. 9 are among the best. The most serious source of inaccuracy was found to be the variation of the speed and excitation of the alternators. The slow-speed conductor gave no serious trouble, provided that it was kept reasonably warm by passing through it from time to time a strong current for several minutes.

The mean square curves, Fig. 8 and Fig. 9.—Fig. 8 represents the mean square curves of current (full line) and of potential (dotted line) when there was no receiving apparatus present. The impressed E.M.F. was 234 volts and the frequency 610 P.P.S. There were 24 coils in series, hence an equivalent of 240 miles of long-distance telephone wire mentioned above. The current curve represents a little over one-half of the theoretical current

curve in Fig. 2. The curve of mean square of potential is not given in Fig. 2.

The abscissæ 1, 2, 3, . . . measure the number of the coil in front of which the reading was taken. Thus abscissa 1 means that the current reading was taken when the slide had the position indicated in Fig. 7[a] and plug I was removed. Hence this reading represents the value of current between the machine and the slow-speed conductor. Voltmeter reading taken in this position of the slide represents, of course, reading 2. To get the voltmeter reading 1 the slide $M\ N$ had to be moved one peg to the left and the connecting plunger left in I. There were 24 coils in series, hence reading 13 representing the reading between coils 12 and 13 gives the reading at the middle point of the loop. Here



p. p. s. 610

M (η^2)	M (V^2)	COIL
63	178	1
67	190	2
64	256	3
53	400	4
37	484	5
18	506	6
4	480	7
3.5	400	8
9.5	256	9
20	134	10
35	40	11
37		12
41		13
41	60	14
34		15

FIG. 8.

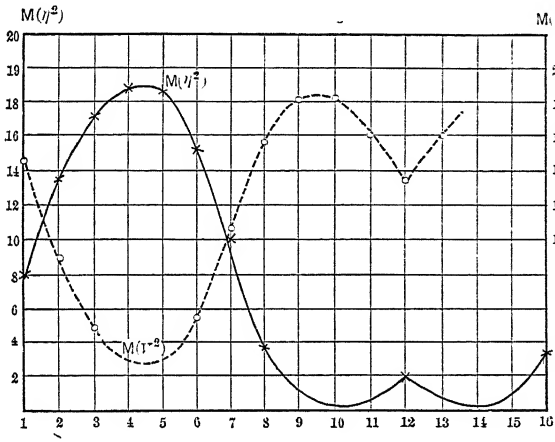
the $M(\eta^2)$ is a maximum and $M(V^2)$ is zero, as required by theory. The voltmeter did not read below sixty volts, hence no $M(V^2)$ readings could be taken in the immediate vicinity of the middle point. But the lowest readings were carefully determined on each side of this point, and the course of the $M(V^2)$ curve in this vicinity is thus fixed. The column headed $M(\eta^2)$ in the table on the right of Fig. 8 gives the electro-dynamometer readings just as they were read off the instrument. The figures in column headed $M(V^2)$ represent the first three figures of the voltmeter readings squared. These curves agree remarkably well with the curves given by theory, in fact much better than one would expect from the apparent complexity and the apparent multiplicity of the apparatus employed. But it should be

observed that the actual experimental operations involved after everything has been once set up are extremely simple and capable of great precision. The maximum of the middle point of the M (η^2) curve is not exactly at 13 which shows that the two sides of the slow-speed conductor were not perfectly symmetrical.

The determination of wave-length and of the velocity of propagation.—The distance between the maximum in the vicinity of reading 13 and the minimum in the vicinity of reading 8 represents a quarter wave-length. Now this distance is 29 divisions, and since each division represents 2 miles it follows that the wave length

$$\lambda = 232 \text{ miles.}$$

$$v = \lambda\, T = 232 \times 610 = 141520 \text{ miles.}$$



COILS	M(η^2)	M(r^{-2})
1	8	144
2	13.5	90
3	17	46
4	18.5	0
5	18.5	0
6	15	56
7	10	104
8	3.5	156
9	0	182
10	0	182
11	0	161
12	2	137
13	0	164
14	0	
15	0	
16	3	

FIG. 9.

Calculating v from the formula

$$v = \frac{2\pi}{T}\,\frac{1}{a}$$

we obtain

$$v = 141480 \text{ miles.}$$

The agreement between the observed and the calculated value is so remarkable that one is much tempted to attribute it to luck rather than to good management. That such is actually the case is admitted here frankly, but it should be observed, in justice to the method, that a large series of curves obtained with different frequencies and under different conditions support the belief that with careful precautions and a reasonably well made and care-

fully nursed slow-speed conductor this method is actually capable of determining λ and v with much accuracy, in fact a greater accuracy than is usually obtained in wave-length determinations of the Hertzian waves. The measurement of T introduces the largest error, but this error will not cause a disagreement between v observed and v calculated since the same T is used in both cases.

The curves in Fig. 9 represent the mean square values of the current and of the potential when a coil with a coefficient of self-induction of one henry was placed in the middle. There were 22 coils in series; the frequency and electromotive force were the same as in the preceding case. The cusp predicted by theory (see Fig. 3) occurs therefore at reading twelve, that is, between the eleventh and twelfth coil. A comparison between Fig. 9 and Fig. 3 shows a very satisfactory agreement between

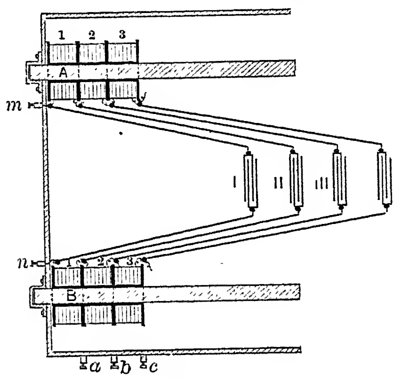


FIG. 10.

theory and experiment. The emormous sag of the current in the vicinity of the receiving apparatus is due to the high frequency and the large self-induction, and therefore large reactance of the receiving coil. The power delivered to this coil is not small in spite of the diminished current, for it will be seen from the $M(V^2)$ curve that the potential is high in the vicinity of the coil where the current is small.

The slow-speed conductor just described cannot stand high voltage and, besides, its leakage is large unless handled with much care. Another type of slow-speed conductor which does not have these objectionable features is represented in Fig. 10 and Fig. 11. It consists of a large number of equal spools 1 2 3 . . . . connected in series. Fig. 10 represents a part of two rows of these spools, each row mounted on the same tube, one for each row. These

tubes are marked A and B. From each wire connecting two consecutive coils runs a wire to a binding post leading to a section of a condenser; these sections are denoted by I, II, III, etc., in Fig. 10. There are as many of these sections as there are coils, and they are all equal to each other. Each coil has as nearly as possible the following constants

$$L = .0125\ H.$$
$$R = 2.5 \text{ ohms.}$$

The capacity of each condenser section is .025 microfarad. Each coil with its condenser section is equal to $2\frac{1}{2}$ miles of telephone wire mentioned above. Two rows of 40 coils each with corresponding condenser sections are mounted together and enclosed in a dust-tight glass case. Such case represents a loop of 200 miles

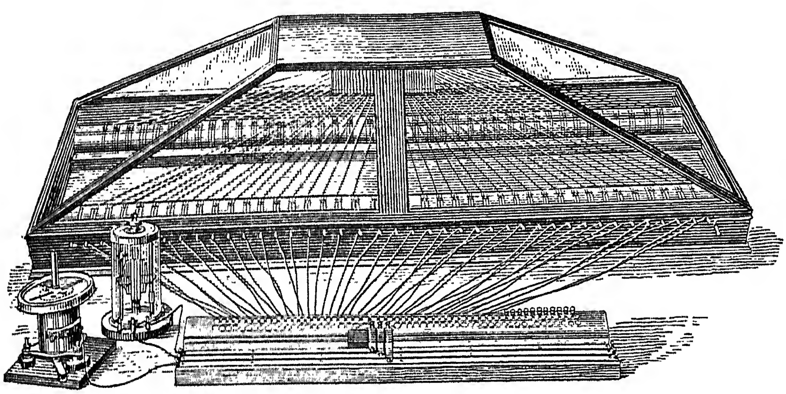


FIG. 11

of long-distance telephone wire. The electro-mechanical laboratory of Columbia University has five such cases and these represent together a loop of a thousand miles. Fig. 11 is taken from a photograph of one of these cases. The two rows of coils are seen near the bottom of the case. The square box near the top of the case is the condenser box with the condenser sections. The wires running radially from this box are the wires connecting the condenser sections to the coils. The condenser sections and the coils can be connected in two ways, both of which were discussed in Section II and illustrated by Fig. 4 and Fig. 5 of that section. In the first arrangement, Fig. 4, half as many condenser sections are required as in the second and, therefore, the capacity per unit length of equivalent wire will be smaller. The theory given in Section III states that up to about 1,000 P.P.S. such

a loaded conductor will be equivalent to a uniform air line. Experiment confirms the theory, for it shows that $M\,(\eta^2)$ and $M\,(V^2)$ curves obtained with such a conductor are the same as those given in Fig. 8 and Fig. 9, at any rate up to 750 P.P.S.

This loaded conductor offers advantages of more exact and more solid and durable construction. The spools can be wound so accurately that the difference in self-induction and resistance between them is exceedingly small. The condenser sections are made of tinfoil and selected mica and adjusted carefully. Two consecutive condenser sections will differ from each other in capacity by as much as even three per cent., but then the average capacity of forty such sections will be very nearly equal to the average capacity of the consecutive forty sections. It is this average capacity which determines the wave-length and the velocity of propagation. The capacity of these condensers remains practically constant. They can stand 3500 volts with impunity.

Laboratory for Electro-Mechanics.
Columbia University, New York, March, 1899.

AMERICAN INSTITUTE OF ELECTRICAL ENGINEERS.

NEW YORK, April 26th, 1899.

The 133d meeting of the AMERICAN INSTITUTE OF ELECTRICAL ENGINEERS was held at 12 West 31st St., this date, and was called to order by President Kennelly, at 8.15 P. M.

THE PRESIDENT:—The Secretary will read the announcements for the evening.

THE SECRETARY:—At the meeting of the Executive Committee this afternoon, the following Associate Members were elected.

Name.	Address.	Endorsed by
CLEMENT, JOSEPH	Consulting Electrical Engineer, Messrs Eckstein & Co., and Rand Mine., Box 149, Johannesburg, S. A. R.	J. W. Kirkland. S. Dana Greene. W. L. R. Emmet.
ELLIS, R. LAURIE	Assistant to Superintendent, Augusta R'way & Electric Co., 230 Dyer Building, Augusta, Ga.	A. M. Schoen. W. E. Moore. R. W. Pope.
ELLIS, JOHN	Manager, The Lonsdale Co's., Electric Light Plant, Lonsdale, R. I.	Chas. R. Cross. W. L. Puffer. R. W. Pope.
GANZ, ALBERT F.	Assistant Professor, Physics and Applied Electricity, Stevens Institute; residence 612 River St., Hoboken, N. J.	Henry Morton. W. E. Geyer. J. E. Denton.
KENNEDY, A. P.	Electrical Engineer, Norton Bros., Maywood, Ill.	H. B. Smith. R. W. Pope. W.E.Goldsborough
LAWRENCE, W. H.	Assistant Superintendent, Second District, Edison Electric Illuminating Co., 49 West 26th Street, New York, N. Y.	J. W. Lieb, Jr., Arthur Williams. Philip Torchio.
LYFORD, OLIVER S. JR.,	Chief Engineer, Westinghouse E. & M. Co.; residence, 916 Lilac St., Pittsburg, Pa.	Chas. F. Scott. J. C. Chamberlain F. B. Badt.
MASSON, RAYMOND S.	Salesman and Engineer, Westinghouse E. & M. Co., Mills Building, San Francisco, Cal.	F. A. C. Perrine. F. F. Barbour. Clarence L. Cory.

NAMBA, M.	Professor of Electrical Engineering, University of Kioto, Kioto, Japan.	E. A. Merrill. E. E. Higgins. H. W. Blake.
PECK, JOHN S.	Electrical Designer, The Westinghouse E. & M. Co., Pittsburg, Pa	Chas. F. Scott. P. A. Lange. A. J. Wurts.
REED, WALTER WILSON	Electrical Engineer, in charge of the electrical work of new plant Citizen Electric Light and Power Co., Houston, Texas. With General Electric Co., Schenectady, N. Y.	Theo. Stebbins. W. L. Puffer. Geo. W. Davenpo
SCHURIG, EDWARD F.	City Electrician, The City of Omaha, 306 City Hall, Omaha, Neb.	H. Vance Lane. W. F. White. R. W. Pope.
SKINNER, CHARLES EDWARD	Electrical Engineer, Westinghouse E. & M. Co.; residence, 424 Franklin Ave., Pittsburg, Pa.	E. E. Keller. P. A. Lange. Chas. F. Scott.
SWOPE, GERARD	Electrical Engineer, Western Electric Co., 242 So. Jefferson St., Chicago, Ill.	H. H. Wait. Chas. D. Crandal E. P. Warner.
WELLS, WALTER FARRINGTON	Assistant General Manager, Manhattan Electric Light Co., residence, 72 East 77th St., New York, N. Y.	E. A. Leslie. E. W. Rice., Jr J. W. Lieb, Jr.
WIDDICOMBE, ROBERT A.	Engineer, Western Electric Co, residence, 1653 Roscoe St., Chicago, Ill.	E. P. Warner. L. K Comstock. F. B. Badt
YOUNG, WALTER DOUGLAS	Electrical Engineer, B. & O. R. R., Roland Park, Baltimore, Md.	O. T. Crosby. H. J. Ryan. Edw. L. Nichols

Total, 17.

The following Associate Members were transferred to fu membership:

Approved by Board of Examiners, March 10th, 1899.

CHUBBUCK, H. EUGENE Manager, Quincy Lighting Companies, Quincy, I
BARSTOW, WILLIAM SLOCUM General Manager, Edison Electric Illuminating Co Brooklyn, N. Y.

THE PRESIDENT:—The subject for the evening is a topical di cussion upon "The Limitations of Power Sub-Division by Electr Motors in Manufacturing Establishments," and Mr. Gano S Dunn who has had considerable experience in this direction wi oblige us by opening the discussion.

A Topical Discussion at the 133d Meeting of the American Institute of Electrical Engineers, New York, April 26th, 1899, President Kennelly in the Chair.

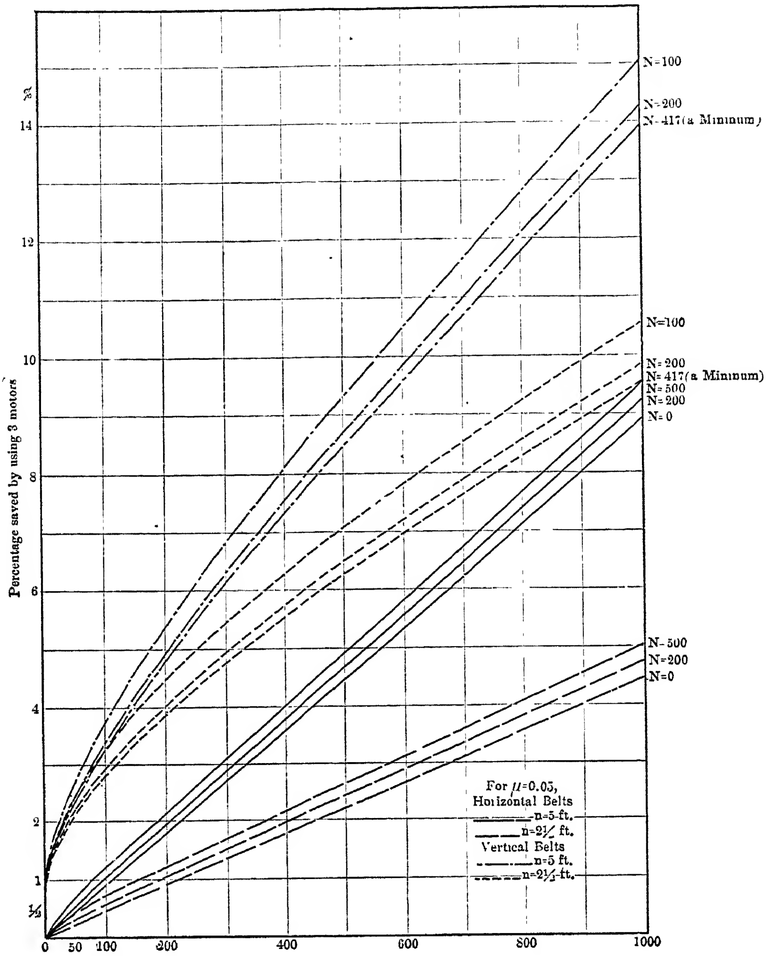
THE LIMITATIONS OF POWER SUBDIVISION BY ELECTRIC MOTORS IN MANUFACTURING ESTABLISHMENTS.

[A Topical Discussion.]

Mr. Gano S. Dunn:—Mr. President and gentlemen: Stated concretely, I should say that the topic of this evening is: "given a manufacturing establishment to be equipped with electric power, shall we put in a few large motors or a number of small ones of the same aggregate capacity?" The question should be tested in regard to the following points: First, which way would be most economical of power? Second, which way would be most economical of first cost? And third, which way would be most convenient?

The economy-of-power question divides itself into two parts, first as the economy is affected by the distribution pure and simple—the problem of taking your power from where it is generated and distributing it over the shop; and second as the economy is affected by the manner of using the tools.

To analyze the first part of this power-economy question, I have had prepared some data and curves [Fig. 1] which I think settle it, since it is very easy to make accurate determinations of just what the friction would be in the case of one large motor driving a shop, and what it would be in the case of a number of smaller ones driving subdivided shafts. My assistant, Mr. Douglass, has been kind enough to put these facts into a formula. and I have before me some curves plotted from them. I have taken as cases for comparison, one large motor and three motors of equivalent horse power. I have put the problem as whether we would have 100 feet of shafting driven by one motor, or three groups of $33\frac{1}{3}$ feet each driven by three smaller motors. Taking a duty upon the shaft of one horse power delivered for every five feet of its length, which corresponds to light machine shop practice, and taking a coefficient of friction at five per cent., which is given in Kent's Handbook for some actual cases, taking a speed of 200 revolutions per minute, and for the first case one in which the belts driven by the shaft, pull hor-



Horse-Power Distributed.

FIG. 1.

Economy of subdivision of power. Per cent. of power saved by using three motors of equivalent power instead of one.

Power distributed equally in both directions from motors.

H = H. P. of the one motor.

N = speed of shaft, R. P. M.

n = ft. of shaft per H. P.

μ = coefficient of friction.

For horizontal belts, equally distributed on both sides of shaft,

$$\% = 0.895\,\mu\left[\frac{H}{n} + 0.020\,H^{1/3}N^{2/3}\right]$$

For vertical belts, taking total belt-pull equal to $3 \times$ effective belt-pull, motor-belt speed 3000 ft. per minute and machine pulleys 12 in. diam.,

$$\% = 0.895\,\mu \times \left[\frac{H}{n} + H^{1/3}\left(0.0679\,N^{2/3} + 56.6\,N^{-1/3}\right)\right]$$

$$\text{Shaft diameter} = 3.7\sqrt[3]{\frac{\frac{1}{2}H}{N}}$$

25 lbs. of pulleys per H. P.

izontally in opposite directions, so that the only cause for friction is the downward pull of the weight of the shaft and its pulleys, we find on consulting the curve that the percentage saved by using three smaller motors instead of one large motor is, for a distribution of 200 horse power, two per cent.

For a distribution of 50 horse power, the saving is about one-half of one per cent. A reason why this saving is so small at these low powers is because we cannot reduce the diameter of our shaft beyond a certain point when we reduce the amount of power it has to transmit. All of these shafts for motor powers under 25 H. P. have been figured at 1½ inches in diameter irrespective of what they have had to do. When we reduce the size of our motor and cannot correspondingly reduce the size of our shaft we cannot make the savings that a reduced shaft would permit. When we go up to as high as 800 horse power the saving amounts, with horizontal belts, to 7.4 per cent. Taking for the second case, that in which all the belt pulls are vertically downward and thereby contribute to the friction, the figures come out as follows: It is assumed that the downward pull of a belt is three times the pull necessary to transmit its power, which allows for the tension of its idle side. In this case the saving for 200 horse power at a speed of 200 R. P. M. and other constants as before, is 5 per cent, and for 800 horse power 12.1 per cent. This is all.

It is obvious that in the smaller sizes of motors which is what we have principally to do with, a saving of 1½ or 2 per cent is very easily offset and possibly reversed by a difference in efficiency. Motors of 10 horse power to 50 horse power do not, however, differ very much in efficiency, even at partial loads, at which points the efficiencies should be taken. So I think it may be safely concluded that for a case of this kind there will be no power saved when we distribute our power divided into three groups of independent shafts instead of having it one continuous shaft driven by a single motor of larger size.

The second part of the power-economy question is: If we cannot directly save anything by dividing up our shaft, can we make any savings indirectly? And the answer is that we can make very large ones. If we have a shaft of 100 feet in length, that shaft has to be kept running whether the tools operated by it are running or idle, but if it is divided into three groups, we can shut down one group or two groups that may be idle and thereby make a great saving. You are all undoubtedly familiar with the work Professor Benjamin has done in this line.

He showed that in six machine shops where heavy machine work was done, an average of 62.3 per cent of the power produced was used in driving the shafting only. In one case he found it as high as 80 per cent. This is because the shafting has to be built large enough for, and has to be kept running for, tools that are idle. People think that tools in a machine shop

are not idle very much. But it is a fact shown by careful observations that have been taken, that even in the busiest shops, the busiest tools are seldom in operation for more than 80 per cent of the time, and I think it is a safe statement to make, that the average tool in an ordinary machine shop is not actually running more than one-third of the time. The tremendous gains that electric power permits come from taking advantage of this idleness of the tools. When we have our single shaft we cannot take advantage of it. When we have our three groups of shafting we can, and we make thereby a large saving.

From the economy-of-power point of view we might sum up by saying that three shafts save little or nothing in distribution, but they save anywhere from 15 to 50 per cent by virtue of their permitting advantage to be taken of the idleness of tools.

Proceeding to the second test of our question which is that of economy of first cost, it is of course commonly known that motors as they get smaller cost more per horse power, and when we have three motors to do the work of one, it makes the total cost considerably greater.

RELATIVE COSTS OF ONE-MOTOR AND THREE-MOTOR ARRANGEMENTS FOR VARIOUS POWERS.

Length of Shaft at 5 ft. per H. P.	ONE MOTOR.		THREE MOTORS.		Increased Cost over one-motor arrangement. Per cent.
		Cost of Motor and Variable Element of Shafting.		Cost of Motor and Variable Element of Shafting.	
10 ft.	2 H. P. Motor, 1½" Shaft.	$151.	⅔ H P. Motors 1½" Shaft.	$260.	70
50 ft.	10 H.P. Motor, 1½" Shaft.	$367.	3⅓ H P. Motors, 1½" shaft	$585.	59
4 ft. per H. P. 200 ft.	50 H P. Motor, 1⅞" Shaft.	$1230.	16⅔ H. P. Motors, 1½" shaft	$1580.	28
3½ ft per H.P. 350 ft.	100 H.P. Motor 2⅜" Shaft.	$2570.	33⅓ H. P Motors, 1⅝" shaft	$2505.	Decrease 2

I have had figured out, and give in the table the first costs where various quantities of power are delivered by one motor, and by three motors, and the percentages that the costs of the three motor combinations bear to the one motor standards. Taking a two horse motor and including not the whole cost of the shafting, but only that part which would vary with a change in the size of the motor, the cost of such an equipment with one motor set up would be $151. With three two-thirds horse power motors the price would be $260, an increase of 70 per cent. in first cost against the subdivided power. Taking another case in which the

original motor is 10 horse power, the cost would be $367 while the cost of three motors of $3\frac{1}{3}$ horse power each would be $585, an increase of only 69 per cent. gaining, as you see, on the first figure. In the case of a 50 horse power motor, still larger, the cost is $1230; the cost for the three equivalent motors $1580, a difference of only 28 per cent. In the case of a 100 horse power motor, the cost is $2570, and the cost of the three equivalent motors of $33\frac{1}{3}$ horse power is $2,505. The figures have crossed the line and show a gain of 2 per cent. in favor of subdivision. So for 100 horse power the question of whether we shall subdivide or whether we shall use it distributed from one large unit is equal as regards first cost.

These figures that I have given may not be absolute, as they have been taken, not so much to give exact data, as for the purposes of comparison, but for purposes of comparison I believe they are strictly correct.

Lastly, with regard to the test of convenience. I should say, in the first place, that half of the motor business would be controlled at once. The question of convenience is often absolute. If we wish to equip a traveling crane with motors, there is only one size of motor we can use for that crane; we have no choice whether to subdivide or not. Also if we have a saw or a punch press, or a large tool, we have no alternative but to use the size of motor that the tool demands. Therefore there is no need of discussing subdivision. The question is ruled out. I would repeat that at least one-half of the installations we have to deal with, are settled already for us by this question of convenience or practicability without any calculation or figuring on our part. It is also my experience that first cost becomes insignificant and disappears in comparison with the gains that are made by consulting convenience of operation.

I have made some figures on the value of the annual product of a number of important works in this country, and I will compare them with the value of the power used in making that product. The method I have taken to get this value, may be criticised, but I think you will agree with me it is about the only one available, since large concerns are loath to announce or to publish the volume of their business, the volume of their sales. I have assumed that material is twice as valuable as labor, and therefore that the total output is three times the value of the labor. Knowing the number of hands that are employed in these various works, and assuming that in American machine shops the average pay of an employee is $10 a week—it is found to come very close to that,—I have figured approximately the value of the product that these concerns turn out. I also have the amount of power that they use. The percentage that the value of the power figured at $40 per H. P. per year bears to the value of the product, is as follows:

Ratio of Value of Power to Value of Product.

Union Iron Works,	$\frac{3}{4}$ of 1 per cent.
Baldwin Locomotive Works,	1.8 per cent.
William Sellers and Co.,	1 per cent.
Pond Machine Tool Company,	1.2 per cent.
Pratt and Whitney,	$\frac{1}{2}$ of 1 per cent.
Brown and Sharpe,	$\frac{8}{10}$ of 1 per cent.
Yale and Towne,	$\frac{6}{10}$ of 1 per cent.

We can see from these figures therefore, that the power that goes into the product is a very small item in itself, and that any savings we may make in that power are unimportant. If we save half of it, we do not save much more than a quarter of one per cent. of the value of the product. But here is the vital point. By introducing a system which saves our one-quarter of one per cent. in this power, we may make from 5 to 50 per cent. saving in the cost of the product that is turned out,—a saving from 20 to 200 times as great as the initial saving which brought it about. At this rate we can afford to buy new motors every year, and throw the others away. We can afford to disregard entirely the question of the power saved, or the economy of first cost. I think this aspect of the question has not been sufficiently brought out.

I do not wish to take more than my share of the time in this discussion, but I will cite one or two instances of what I mean. In the case of a machine shop built in the modern style, where they wish to have clear head-room for a crane to carry quickly heavy pieces of machinery from one tool to another, the question of overhead belts or of belts running slantingwise from the side galleries down to the tools, which was one of the ways in which it used to be done, is ruled out at once by the fact that when we are able to put a motor on a big tool on the floor of such a shop, no one in his senses would consider driving it by belts, and obstructing the head-room. The clear head-room would save perhaps 5 per cent of the value of the labor of the shop,—in making it possible to take heavy machinery and pieces up and down it and into its various bays without stopping to clear the belts. In regard to the speed of tools we are so accustomed to having the cone pulleys which give us certain definite speeds, on our lathes and cutting tools, that we do not yet appreciate what great advantage we can get from electric motors which will give us graded speeds between those that the cone pulleys would give. In many cases where a chip is being taken, stopping to change the cone makes a defect in the work and sometimes lets the chip cool off.—I have recently seen chips being turned red hot— and necessitates a resetting of the tool. With an electric motor arrangement, very easy and smooth gradations of speed may be obtained, without jerks. This alone means a great increase in output.

The Government Printing Office in Washington is the largest printing establishment in the world, \$11,000 a day being required

to run it. It used to be operated by overhead shafting, belted to the presses and other machinery below.

If we should drive this same overhead shafting by large motors we would unquestionably make a saving of power over belting it back to the engine room, but we would not make the indirect savings peculiar to the electrical system. But if we subdivide and place a motor upon each press, we at once derive enormous advantages.

This is what has actually been done in Washington, and it results in increasing the output of the Printing Office 15 per cent. without increasing the speed of the presses. The reasons are, that with direct-connected motors the driving is absolutely uniform, which makes possible the preservation of what is called the register of the presses, which is the accuracy with which they will fold a sheet into eight or sixteen pages after it has been printed. With belt driving, on account of the different degrees of slippage at the moment of impression, resulting from atmospheric conditions, and inequalities of speed resulting from the wabbling of the belt to the crown of the pulley and off again, considerable irregularity is introduced, which makes preservation of register more difficult.

Also in "making ready," that is, preparing the press to print, by making a great many trial impressions and adjustments, the remarkable facility of control of electric motors which may be started, stopped, reversed, moved very slowly or very rapidly, permits this tedious operation which requires a number of hours, to be done much more quickly than where the control has to be effected by slipping a belt on and off a loose pulley. The saving of waste of paper and labor resulting from the absence of overhead gear that churns up the dust, and drops oil upon the presses and their work, also contributes to this increase in output.

All of these advantages do not involve the question of power, but are results of the greater convenience in direct-connected motors over belted ones. It can be readily seen that in the Government Printing Office the question of the limit of power subdivision would never be raised. The 15 per cent. increased output would pay many times over for whatever difference there would be in the first cost.

I would make the following conclusions:

First:—Where we have to decide whether we shall install one large motor or a number of smaller ones, I would give preference to the smaller motors down to a limit of 5 H. P. for light machine shop duty, and 10 H. P. for heavy machine shop duty. This for cases in which the problem is one of distribution only.

Second:—Where the introduction of motors would have any effect upon the product, I would dismiss entirely the question of power and decide solely with regard to the convenience of operation afforded, and would not hesitate to put in the very smallest motors, mounted upon any kind of machinery, notwithstanding

their greater cost and lower efficiency, if they even to but a slight degree increased the product of the labor of the shop. Gains in this direction cause other gains to sink into insignificance.

MR. R. T. E. LOZIER :—The subject for discussion to-night is a very broad one. It covers a very large field. The question comes up whether the use of individual motors in all cases is desirable. I do not think that that general proposition holds true. The conditions governing the operation of machines enter very largely into the problem. The equation is one that is rather complicated and made up of a number of factors. I do not think that the general proposition can be held that individual motors applied to all machines, whatever their nature, is desirable.

If we separate the cases, there are a number to be taken into consideration. The general machine shop, one in which a number of tools of different types and sizes are used, such as Mr. Dunn has described this evening and given some very valuable data upon, is perhaps one of the most common ones. The printing press room is another one, and the cotton, silk and woolen mills, in which different forms of looms are used, all come under consideration. I think that the last instance is one in which we have got to wait for the future development of electric motive power. As concerns the first two, the machine shop is something that we are developing gradually. The printing press is beyond the state of development. I think that it has been clearly demonstrated that the individual motor throughout the printing establishment is the desirable method of applying power, for this reason :—In the printing press establishment, the question of cleanliness is paramount. The question of speed control is of very great value. All of these affect the product. As Mr. Dunn says, in the Government Printing Office at Washington, perhaps one of the finest examples of individual motor application, they have increased their output by 15 per cent. I verified that general figure myself by experience, and it is undoubtedly true that the man who buys individual motors in a case of this kind, pays for his equipment before the end of the year. As concerns the machine shop, which is a very interesting problem, one that we are all busy with, the general lay-out of the shop I believe governs the case. The shop is probably divided into two sections,—the main part of the shop, the nave, in which the traveling cranes are most commonly used, and the coves.

I think that we are all prepared to agree to the general proposition that the large tools that are set out in the middle of the shop in the path of the traveling crane should have their individual motors so located that the crane will be accessible to deliver and handle the material. We have lately made a large equipment in which we have done more than introduce the general form of large tools in the middle of the shop; that is to say,—we have brought the lathes and small drill presses out into

the middle of the shop, where the traveling crane can also deliver to those tools (see Fig. 2). We have gone further than that and have put individual motors on every tool throughout the shop (see Fig. 3). Every tool in the shop which I have in mind has an individual motor on it. The general effect is remarkable. It is almost impossible to comprehend the appearance of a shop of that nature to those of us who are accustomed to an ordinary belted plant. The shop is very light and very clean. The general ventilation is excellent, the absence of dirt, etc. is very evident. In addition to that, the speed control, which Mr. Dunn referred to, is a very important feature. The men become accustomed to handling their

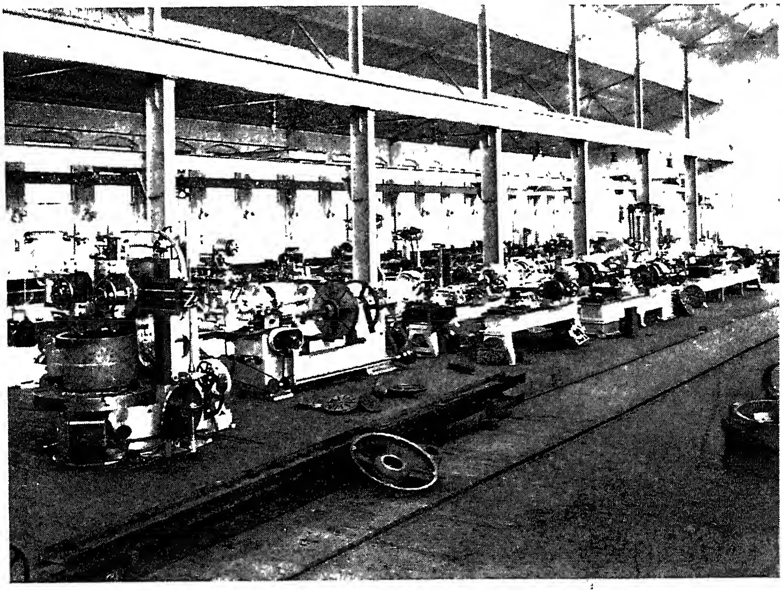


Fig. 2.

tools in a very much better way. The product is not only produced at a higher rate, but the product itself is very much better. That applies particularly, if I may deviate for a minute, to the printing press industry where the run of the paper has a great deal to do with it—the nature of the work, whether it is half-tone work or ordinary type work—the condition of the ink—these all enter into the product, and they vary throughout the day sometimes, so that if the operator has within his own control the means of changing the speed very readily, he can adapt the speed of his presses directly to the different constants or to the different factors that go to make up

the product. That also applies to machine-shop work, and that leads up to a very important consideration in this whole question of power transmission,—that is the method of controlling the speed of the machines. In ordinary machine-shop practice the range of speed of the machines is very great, and it is a very difficult one to cover, because as the speed runs down, the torque sometimes increases. A large lathe running at a slow rate and having a heavy piece of work on, the torque of the motor is increased, and the cutting of the tool is also at a greater duty, and you cannot use the common methods of straight armature resistance and field commutation, so that we have got to get some good system of speed regulation; that is essential. It means that in laying out equipments of that kind, you have got to have a comprehensive scheme of distribution and regulation. It has got to apply to the entire equipment. I do not believe that you can use the methods which have been customary, although not exclusively employed in the past.

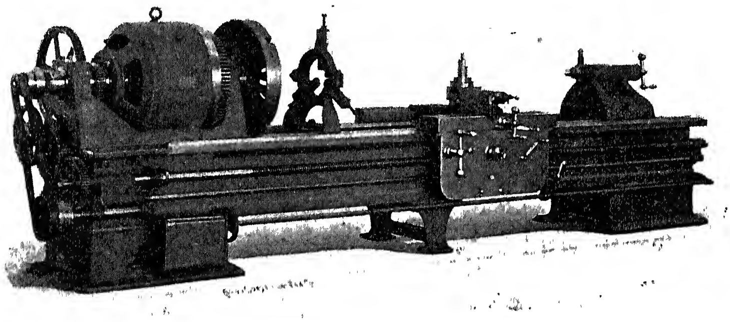


FIG. 3.

With the system of speed variation applied to individual motors, you get the improved product at a higher rate. You get excellent light and ventilation. The tools are kept in better shape by virtue of the fact that the general state and condition of the shop is improved. The men get accustomed to doing better work. The *esprit de corps* seems to be raised. The dropping of dirt and oil is not so great, and you can paint your tools, for example with this alumina pegamoid (such as the letter boxes are painted with). The general effect of the shop is very much improved throughout. I should like to read you an answer to a letter that I have, referring to the practical operation of this shop using individual motors, that I have in mind. I put certain questions to the superintendent, and I will read these points just as they occur. I asked him this general question, "Whether "all tools in a conglomerate tool shop should have individual "motors?" The answer is this: "The results and advantages "of a shop operated by individual motors are, that when no work

"is being done, no power is being consumed; more perfect speed "control can be obtained, and the operator always has at his "command the full limit of his machine." *** I think that this is a very important point. I think that if Mr. Dunn's analysis of the matter is followed out, it will be found that the cost of the equipment becomes insignificant because of the increase that it is possible to obtain in the product of the factory due to the improved methods of speed control. It might be looked at in another way perhaps; the percentage of the cost of the power to the cost of the product is very small; but the saving in power will probably represent a considerable interest on the investment for the motor equipment.

*** "More perfect speed control can be obtained and the "operator always has at his command the full limit of his ma-"chine. Simply by moving a lever he stops, starts or reverses "and also gets a wide range of speeds without any other move-"ment on his part except to handle the lever which can be "arranged to be immediately under the operator's hands." ***

It is also possible to get a very much greater number of speed increments. The average cone pulleys I think have as a rule about six variations, while with some of the improved methods of motor control these can be increased to eight or ten.

*** "This I consider the principal advantage of the system. "Operators on belt-driven machines will allow their machines to "operate at speeds that are not suitable to the work in hand, "rather than go to the trouble of shifting the belt; while on "the other hand, by simply moving the lever, they can alter the "speed and can handily do this. Another advantage is that the "head-room over the machine is left unhampered. Machines "may be set where they may be served by traveling cranes to "the best advantage. Another incidental advantage is that ma-"chines can be moved from place to place very readily, as all "that is necessary is to change a few connections."

I have seen that point exemplified in a number of cases where in machine shops the machines have to follow the exact lines of shafting and belting. Sometimes they place their machines at inconvenient points, where, if they have the individual motors, the shop can be arranged at will. It very often happens that the growth of the business is such that machines that were conveniently located at one time become inconveniently located, and the space which they occupy, and particularly in the case of large tools, is wanted to be occupied by smaller tools. Then these larger tools can be readily moved to points of greater advantage. Often times these points are in nooks and corners of the shop, where while it is not impossible to reach them by belting, still it becomes awkward to do so.

My correspondent continues:—

"Another advantage is the cleanliness of the shop, and this is "of no minor importance. It is well known that belts cause

"circulation of air in the shop which deposits dust particles on "walls and ceilings."

I asked him what the item of repairs and maintenance was in a shop using individual motors, and he says "That it is no more "in a shop equipped with motors on every tool, than with a belt-"driven outfit, provided that the motors are in the first place "adapted to the work." The adapting of the motors to the work is something that is coming along, I think, as the business progresses, because when the power has once been determined it is a constant, and that size of motor can always be employed for performing that work on that particular tool. That leads up to the question of how much difficulty there was in obtaining tools built for individual motors. This shop that I have in mind has grown very rapidly, and they have had to buy tools on short notice, and the question came up in my mind, or at least I thought it best to ask the question, if the inconvenience in waiting for these special tools was sufficient to offset the advantages that were obtained from the use of these individual motors. The answer is this: "We have some difficulty in obtaining tools built "for individual motors, but this will gradually eliminate itself as "the demand increases." *** That is to say, the tool builders, as the printing press people are doing, will begin to adapt the head stocks and the driving gears of their machines to these motors; so that a man can order either a belt-driven tool or a motor-driven tool, as the case may be, and get it just as quickly. It is going to be inconvenient in changing over from the old school to the new, but in the case in point the difficulty has not been insurmountable. They have been able to overcome it.

*** "In fact most builders are willing to make the necessary "changes at the present time, at least all of the enterprising "ones." As stated before, the speed control is far superior to the belt system not only in its range, but in the ease of adjustment. I then asked the question: "Would you return to the "belted system under any circumstances?" The answer is, "I "would not return to the belted system under any circumstances. "This I consider, however, no argument, as it is only the expres-"sion of a prejudiced person."

The question then came up of whether the geared motor or the slow-speed direct-connected motor appeared to have the greatest advantages, and then considerable follows in which the question of applying the direct-connected motor or the geared motor to various classes of work, and it seems that it depends a great deal on the nature of the work. Taking the question of lathes where the torque increases inversely as the speed; in the larger lathes the direct-connected motor is more adapted, but when it gets down in the smaller sizes of lathes,—20-inch lathes and smaller—the torque is so great, the size of the motor is so large, that it cannot be conveniently placed in the head stock, and consequently a geared motor of higher speed is used, but the

general idea seems to be that each individual tool has got to be considered by itself, and its different features worked out, and there does not seem to be any clear line of demarcation; each tool is a separate proposition, and the form of motor to be applied is governed entirely by the conditions under which that tool operates. In answer he says: "So much for the motors them- "selves as connected with machine shop tools, but the subject of "the greatest importance in connection with this matter is the "supply of electric current." Then he goes on to describe the different schemes of speed control that were tried and comes back to the original proposition that in case of a large equipment composed entirely of independent motors where speed control is desirable, it has got to be taken as a general proposition; it hardly seems feasible to apply the old established methods that we have been following in the past.

This speed control must be obtained either in the construction of the machine or in the method of giving it potentials. The system must be so arranged that this speed control can be obtained in a manner to give the motors a constant torque, irrespective of the speed and with the highest efficiency.

It is also necessary to have some comprehensive system applying to all of the motors of the installation or to such as may be necessary, which will accomplish these speed conditions. It perhaps requires some courage to do this, but the results well warrant the effort, as has been successfully demonstrated in the example that I have cited this evening.

Mr. H. Ward Leonard:—I should like to emphasize a little the fact that rheostatic control is adapted to only a very small line of speed control of motors. Where you have work in which the torque increases in some definite way as the speed increases, as for example, a centrifugal pump or a ventilating fan, a rheostat gives a very nice method of securing the control that is desired, as each particular speed represents a definite torque and the control can be quite perfect, and the speed can be maintained at any speed that is desired. When, however, the torque is independent of the speed, as is usually the case, or where, as in some few instances, the torque varies inversely as some function of the speed, then it becomes of the first importance to see that in a practically constant field you supply the armature with a net voltage which will be available in proportion to the speed, and there are quite a number of ways of securing this result, and two or three methods I have already described before the Institute and there are two or three modifications which I will make a few comments about.

Referring to Fig. 4., s is to represent the generator of constant E.M.F. which for convenience in handling the figures we will call 100 volts, and R is a rotary transformer consisting of three armatures which will revolve continuously across the outside voltage and having the armatures so wound as to create upon a 4-wire

system, constant potentials, such that between the outside wire and the first conductor there will be 23 volts; between the two middle conductors, 33 volts; between the third and fourth, 44 volts; thus giving us available six different constant electromotive forces as follows: 23 volts, 33 volts, 44 volts, 56 volts, 77 volts and 100 volts. This system will be available for operating

SPEED.	DIRECT ROTATION.		REVERSE ROTATION.	
	Lever A on Contact.	Lever B on Contact.	Lever A on Contact.	Lever B on Contact.
0	1	1	1	1
23	2	1	1	2
33	3	2	2	3
44	4	3	3	4
56	3	1	1	3
77	4	2	2	4
100	5	1	1	5

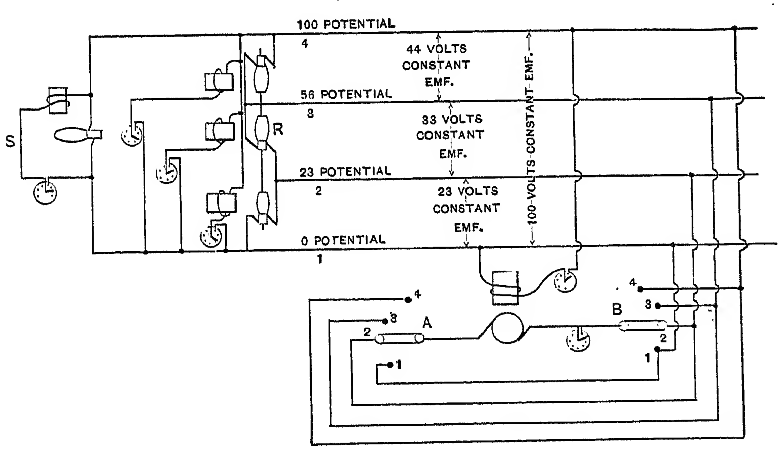


FIG. 4.

the lights in a factory and supplying all purposes which require only a constant electromotive force, and will also give throughout the shop at command these six different constant electromotive forces.

The field of the motor would preferably be wound so as to be connected across the outside wires and would have a field rheostat

for such partial regulation as might be desired in that way, and each one of the four constant potentials represented by the four different wires would be led to different contacts of a switch with a contact lever which would enable you to connect one brush of the motor to either one of the four wires, and similarly to connect the opposite brush to either one of the four wires. Thus you can get upon this armature, while in a constant field, and a field which is independent of the armature current and independent of the opening of the armature circuit, any one of the six constant electromotive forces, and you can get them graded in order, and you can get them reversed. Of course I have shown this in a very crude, simple form; but a controller devised to give such gradations of voltage upon the armature, with intermediate gradations, if desired, of ohmic resistance, will enable you to operate any motors through a manufacturing establishment in either direction at these six different automatic speeds; and generally speaking, if you can get six graded speeds such as this, and can get field regulations to carry you from one to the other, or if desired, rheostatic regulations to secure intermediate speeds, you can fill almost all requirements that are met with in manufacturing plants. The size of this rotary transformer would in all probability, in a large, comprehensive establishment, be, in kilowatt capacity, about 20 to 25 per cent of the kilowatt capacity of the main generator; for you will understand that all motors which are being operated at full speed do not require any of the current that is going through the rotary transformer, and those that are operating at the highest speed affect only a portion of the rotary, and as a consequence, there will be times when one of the sections of the rotary transformer may be operating as a motor, another section as a generator, and so forth. There may be any one of several different conversions going on there, depending upon what conductors the motors are connected across.

Another form of control which sometimes has its uses, is this: Suppose we have the familiar 3-wire system, and that we have 100 volts on each side. Suppose we connect the armature of the motor to be controlled, between the middle wire and one outside wire. Let us call the potentials of the 3-wires of the 3-wire system 0, 100, and 200, and suppose one motor armature is connected between 0 and 100 potentials, so that it is subjected ordinarily to 100 volts constant E.M.F. Now let us place in series with our motor armature across the constant E.M.F. of 100 volts, another armature which is driven constantly at full speed in one direction of rotation and revolving in a separately excited field, which is variable and reversible. Suppose this regulating armature is wound for 100 volts when its field has its full strength. Evidently we can cause the 100 volts of this regulating armature to either assist or oppose the E.M.F. of 100 volts across which the motor armature is connected. Thus we can se-

cure upon the terminals of the motor any E.M.F. from 0 to 200 in a constant field. The amperes through the regulating armature and the motor armature will be the same, but the maximum E.M.F. of the regulating armature will be 100, and the maximum E.M.F. on the motor armature will be 200 volts. That is, the watt capacity of the regulating armature will be only half of that of the armature of the motor to be regulated. A convenient way of operating the regulating armature at constant speed will be by driving it by means of a shunt-wound motor connected across the constant E.M.F. The chief novelty of this scheme consists of starting from an intermediate potential such as that upon the central wire of a 3-wire system and connecting to such intermediate potential, one terminal of a generator of variable and reversible E.M.F. and thus developing at the other terminal of the generator, a new potential controllable over a wide range. This new variable potential can readily be carried beyond the potential of the outside wire of the 3-wire system so that the direction of the current would reverse in a motor armature connected between this variable potential and the potential of the outside wire of the 3-wire system.

Another modification which is sometimes convenient, and which I first put into commercial practice in 1891, at the works of the Eddy company, is to control a machine where, as when some conditions are met with, it is important to have perfect control at very low speeds, but it becomes unimportant to have very good control except at such reduced speed. Under such conditions a large motor can be controlled with a small motor generator, the motor end of which would be connected across the full voltage; the generator end of which would be of few volts and many amperes and so arranged as to supply, in starting and at low speeds, the armature which is going to be operated and controlled, and after you have reached the limit of the speed represented by the low voltage at the generator end of your small motor generator, you step off from that point either to a rheostatic control or something like perhaps the series parallel control, though the rheostatic control is the one that is simplest and cheapest. In the instance at the Eddy works the motor was a 500-volt motor and a motor generator had its primary end supplied with 500 volts, and the secondary end produced as a maximum 100 volts. At that time I was trying to devise schemes for operating large presses and things of that nature in which the control of the press at very reduced speed was a matter of the first importance, but where it becomes comparatively unimportant as to having perfect control beyond the reduced speed; and in the effort to try to secure the reduction in the size of the necessary equipment I put this into use and it worked all right, but the added complication of the switch device which was required, made me believe, and I still believe, that for most instances it is best, on account of simplicity, to spend a little more

money in the beginning and get the most simple equipment possible. Such an arrangement as that described is perfectly feasible, and it reduces the size of the necessary motor generator equipment materially. I wish to point out that quite frequently it may be advantageous to replace the rotary transformer equipment in Fig. 4 with a storage battery, which nowadays has become far more favorably thought of than heretofore, and very frequently may be a feature of an equipment of a manufacturing establishment. Of course when you have a storage battery you have plenty of available points for connection, and can thus create any desired intermediate potentials that you may wish to have.

MR. F. M. PEDERSEN:—I would like to ask Mr. Lozier to explain an apparent inconsistency. If I recollect his remarks correctly he said at their beginning that he did not favor putting independent motors on tools; that is, carrying the system to its extreme by putting a motor on every tool, but that he inclined toward group driving; and yet he spent most of his time in describing a shop in which there is a motor on every tool without exception. I would like to know whether I misunderstood his first remarks.

MR. LOZIER:—My first remarks referred to the general proposition of individual motors on all machines, not necessarily tools, and I went on to specify the machinery, referring to the machine shop, and the printing press shop in which the individual motor seemed to be advisable, and then going on to the weaving machinery, in which the unit of power in each case is very small, and in which the group system seemed to be advisable. One reason for the group system in the case of these weaving machines is the question of the constancy of the speed and the ease with which additional looms can be added. I believe that in a large industry in which one class of machinery, either a loom or something of that nature is used, that the tendency now is to establish a certain ratio between the cost of the motive power and the machine. I think that to-day, although it may not apply later on as electricity develops, and is better known that it can be stated that where the cost of the motor exceeds the cost of the machine that it is to drive, where that class of machines preponderates in an industrial establishment, that it is not commercially practicable to use the individual motor. Where, however, the number of such machines or tools is smaller than the general run of tools in the factory, or whatever industry it may be, then of course that rule does not govern. I think that answers your point.

MR. GEORGE HILL:—I hoped to hear rather more of the discussion before participating in it, because the experience which I have had has been mainly in the line of printing press and bindery work, and while the results are probably applicable generally, as instanced by the results given by Mr. Lozier, yet a

general proposition can not safely be taken from one branch of industry. The conclusion which I have reached after installing the American Book Company plant and watching its operation for nearly three years, has been that in general there is no theoretical limit to the economical subdivision to which we can carry the application of the motor to the machine. There are practical cases, however, such as have already been instanced, in which there is such a limit. In the American Book Company plant we had a great many Smyth book-sewers which required about one-tenth of a horse power to operate. They were all run by operatives on piece work, some of whom were much pleased with the individual motors which were put on, and others were much displeased, and those that did the best work were the ones that were the least pleased, because the little motors which gave a speed of some 55 signatures a minute at the start, dropped after warming up, to about 40, 44 and 45, decreasing the output. We then changed the twelve machines, and drove them by means of a half-horse power motor with a three-quarter inch shaft placed on the floor, giving a speed of 60 signatures per minute, and this was satisfactory. If the motor had been sufficiently perfect to have maintained its speed throughout the entire day's run, the application of the individual motor to the individual machine would have been perfectly satisfactory. In this plant we have a number of $\frac{1}{4}$ and $\frac{1}{2}$ H.P. motors giving perfect satisfaction.

Economically, the American Book Company's plants originally manufactured 14,000 books a day at a fuel cost of about $45, obtaining simply the manufacture of the books. In their new plant the fuel cost is about $8.50 a day; they are manufacturing 22,000 books a day; operating their New York offices, and the general offices of the corporation; lighting the entire building; operating all of the elevators required for the manufactory, (9 stories); and in addition operating two high-speed high-capacity hydraulic elevators, required for the service of the three upper stories by the owners of the building in which they are the tenants, and for which they operate the plant. Our preliminary estimates showed but very little difference between the cost of installing the usual Corliss engine, vertical shaft, and various horizontal shafts on each floor and the electric installation.

Two great difficulties to be met by the designing engineer in plants of this kind I think exist still, I know I found them serious; one was that absolutely no information was accessible as to the amount of power actually required to operate the various machines when in good adjustment. I had hoped to be able this evening to place on record some of my observations there, but a sudden press of business made it impossible for me to get at my data. As an illustration, one of the machines weighing about three tons, a very heavy machine, running at a low rate of speed, was stated by its maker

who had done nothing but manufacture this type of machine all his life, to require about five horse power to operate it. I concluded from my observation of the machine operating with a four-inch belt, that he was very much in error, and I put a half-horse-power motor on and the maximum of current required for the operation of that machine with the largest book that they could put in it was three-eighths of a horse-power. The second difficulty is to know when a machine is properly adjusted. In one of the large Cottrell sheet perfecting presses, the man that erected it claimed that it was in perfect adjustment. It was taking 7½ horse power. I concluded that he was in error, and after considerable wrangling showed him how to use the ammeter and tachometer and finally having to show him where in his press the friction losses were, we reduced the power to four horse power. We put in five Hoe presses. Four of those presses operated very nicely with three horse power, one required nearly five. The Hoe company said " Of course that is in your motor. There is no question about it. The Hoe company does the very best possible work. All of their work is absolutely the same, and if one press requires any more power to operate than the other, it is unquestionably in your motor." Well, we argued it a little bit and finally we took the cylinder out, scraped one of the end blocks a little and put it back again, and we lost that additional horse-power. It came right down to where the others were.

In another plant that I have in mind, the press had recently come from the maker, and was said to be in perfect adjustment, and as an illustration of it the press tender showed me how it worked. It was a belt-driven press and he threw the belt on just for a moment, so as to throw the bed direct into the air cushion and then threw off the belt. The air cushion was quite strong enough to throw the bed back again and into the entrance of the opposite cushion. The power to operate that press was at least two and a-half times as great as it ought to have been, and showed violent fluctuations that were not necessary. The information therefore that an engineer needs in order to intelligently consider the problem at the start, is such that a few engineers have, and which is not generally published, so that he must rely on his own good judgment and expect to make some mistakes in the attachment of the motor to the machine to be driven.

Another interesting experience, perhaps, as illustrating the enormous waste of power in belting, which I had, was primarily occasioned by the endeavor of a certain company to demonstrate the superior efficiency of a very low-speed motor directly connected to the shaft of a press. They had this motor connected up, and in order to compare it they sent down one of their high-speed motors which had a four-inch pinion and was belted on about five feet centers to a 30-inch wheel on an extension of the shaft. They operated first the high-speed motor and then the

low-speed motor with the same form. The result was that the low-speed motor took about one and one-half horse power and the high-speed motor took about two horse power. I suggested that that was not a very fair test, so we raked out of the scrap-heap an old broken gear-wheel that was cobbled up with a piece of scrap-iron on the back and a pinion, and we put exactly the same motor on, gearing it, after which the geared motor took seven-eighths of a horse power as against one and one-half horse power for the slow-speed motor. The American Book Company's plant has a number of both kinds in operation, and the chief engineer informs me that he would very much rather have the geared motor running at relatively high speed than the low speed motor; that it operates more satisfactorily and gives him less trouble and takes a great deal less current. In regard to varying the speeds I think we accept conditions that would be laughed at if offered to the old mill engineer to meet with shafting and belts, and are the outcome of the disinclination of the shop owner to properly equip his shop with machines for the work. With the usual methods we can give as wide a range of speed as is really necessary, cut the coal bills in two at least, and maintain the speed at a uniform rate and this is not possible with belting. It is my judgment that every machine requiring one-quarter horse power or more, should have its own motor, either series or shunt wound, according to its work. If smaller motors are ever built that will maintain a uniform speed for a 10-hour run, install them where needed.

Mr. H. B. Coho:—I recently had a talk with a very prominent manufacturer which led me to believe that this matter of subdivision of power is largely a matter of the amount of money a man intends to invest. The situation is this: They were operating a line of sewing machines with one motor running at about 500 revolutions per minute, directly connected to the line shaft. This motor operated 100 sewing machines and had cost the purchaser about $300 and about $100 for shafting. He was inclined to think that individual motors on each machine was what he wanted, and I made a test for him, putting individual motors on several sewing machines. I found that the 100 sewing machines operating with individual motors would take about 20 amperes more than the motor running the 100 sewing machines from the shaft. These figures are, of course, based on the entire 100 motors being in operation. After I described to him the extra current required he was still interested and desired to go further into the matter. He asked the cost of the 100 motors and I said about $1,800. I thought of course this would kill him, or cause a fainting spell, but it didn't. He calmly remarked, "that represents only $80 per year." He said further, "the whole matter to us is this: What we wish is the least liability to break-down and the greatest convenience for our operators. In depending on one machine we might have a break-down which would be

serious, while with 100 machines we would hardly be liable to have any machine out of service any great length of time." I told him we would be very glad to make the 100 motors. This is the first case of this nature that I have ever had. This leads me to think that purchasers are beginning to look at these matters largely as one of investment, and that, as Mr. Dunn said, the percentage of operating cost is so small in relation to the output, that it is largely from a consideration of the convenience and freedom from accident that will govern the extent to which individual motors will be used.

Mr. Oberlin Smith:—Referring to Mr. Dunn's remarks about the percentage of the cost of power to the product of a machine shop, my experience in the Ferracute Machine Company is that it is about one and one-half per cent. This agrees pretty nearly with some of the other people's figures. In general, in regard to the matter under discussion, some of you may know that I have been talking individual motors as an eventuality for several years, even at a time when anybody was thought somewhat of a crank who did advocate them. Some eight or ten years ago it was very cranky indeed. I still think, and always have, that absolutely individual motors on every machine is the ideal method; I do not say as yet the practical method. Five years ago it was a very impracticable method and we thought then that it was proper to adopt them only occasionally. Now it seems to be becoming more and more the proper thing to put in smaller motors and more of them.

The slow movement of this reform is due partly to the conservatism of the public, which of course will pass away in time. Motors are being not only improved and cheapened but they are being adapted to the particular work that they have to do. In my own practice at present I usually put motors on individual machines where they require about two horse power or upwards; but where they run below that, I try to use the group system. Of course this will depend a good deal on the *kind* of machines. In the ordinary machine-shop, where there are a great many small drill-presses and lathes, taking a fraction of a horse power each, the best present method would seem to me to be, to use as much group driving as can be arranged with those small machines; then on the larger one's using say above two horse power, apply individual driving wherever practicable, or apparently best. Of course there are exceptions to all rules.

In regard to the advantages mentioned by Mr. Lozier, I fully agree with the quotations he read. Other matters that I think were not mentioned were, first, the much greater light that is gotten in the shop; second, cleanliness; third, more room overhead; fourth, and quite important, extra safety. We all know the danger in machine shops of big shafts winding people up; and of belts flying off pulleys; and sometimes of a hanger falling down with shafting, pulleys and other things on men's heads.

We get rid of all this with the electric drive, and have nothing but wires under the floor.

Another geographical advantage, so to speak, besides those that other speakers have referred to, is the ability to put machines away from the natural positions of lines of shafting and not to limit them in direction. With individual motors we can turn the machine around any way. We all know how awkward it is if we have a long narrow shop and a row of lathes standing (as they must) parallel with the line of shafting, to put planers there also,—as planers are usually arranged for belting. Such awkwardness frequently comes in, cutting up passage ways etc. into a sort of maze. With electricity we can stand machines around anywhere, cat-a-corners or otherwise, and move them about freely, without keeping to parallel lines or anything of that kind.

What we badly want is a further reduction in price on small motors. This is bound to come; it is coming rapidly, and will come very much more rapidly than it has so far, when we make motors not by the 50 and 100, but by the 1000 and 10,000, as we do sewing machines and such things, with a great many "special" tools. Then of course the price will be much lower; and the demand and supply have got to react on each other as we go along to bring such a state of things,—but it is coming!

It seems to me that another thing which is holding back the use of motors a good deal, in machine shops especially, is imperfect control. The methods mentioned by Mr. Leonard are very interesting, and it would seem that something of that kind, the running of a number of wires from any proper source, carrying various voltages, as he speaks of, running such group of wires to every machine, and then picking up special voltages as we want them by proper controllers, might very likely be the coming method. This, however, can be left to the electricians to work out. I can tell them, from my mechanical standpoint, that good control is the thing we want worst of all, not only the control of a few speeds at a somewhat varying rate, but of many speeds at a great variation.

Consider the ordinary machine shop, which gives very severe conditions for changes of speed, although not so much for changes of load; take a 20-inch lathe that we want to run at say, about 25 feet a minute cutting speed. If we are turning half-inch work, we want 200 revolutions a minute; if we are doing 20-inch work we want only 5 revolutions. This is a tremendous variation, much greater than any of the ordinary controllers would give, and much greater than any motor can be expected to work efficiently at. Perhaps the remedies will come in this way, that we will specialize our lathes and such machines more; we wont try to run one lathe from 20 inches down to half an inch, but will have one that runs from 20″ to 10″, another from 10″ to 5″ and another from 5″ to 2½″, etc. The electrical men

will not then have to make such tremendous variations of speed. In drill-presses we have a more moderate variation, while in milling machines we have a little, and in planers scarcely any. All these are problems to be worked out; to adapt the motors as far as possible to the present lathes, but also to try and make the lathe makers and users adapt their machines to the electrical conditions, which seem to be somewhat limited in spite of everything.

My experience in this work has been more especially with punching and drawing presses than on other work, and I lately have had a number of motors sent to me to put on presses. Among these were eight large presses using, on an average, from three up to six horse power. We equipped all of these with individual motors, and then we had several smaller presses taking from one-quarter to three-quarter horse power each, which were arranged in groups of four or five with a small motor to drive the group, putting the shaft on the floor so as to keep the overhead space clear.

Since then I have built and equipped a lot of presses for the Navy Yard at Washington for drawing brass shells for cartridge cases for rapid-fire guns of various sizes, from one-pounder up to six-pounder and three-inch. The complete plant, as far as the presses went, was all driven with individual motors, the largest of them 15 horse power and the smallest 5 horse power. Then there were a few trimming lathes which were driven with very small motors.

The conditions in presses are, of course, vastly different from what they are in machine shop work. In the latter the great desideratum is an immense difference in speed and not very much variation in load. In presses, except in a few instances, we need no variation of speed.

There are sometimes little automatic armature notching presses that run from 50 to 200 revolutions per minute and want four to five different speeds, but these are only exceptional cases almost all of the ordinary punching, drawing, cutting, and shearing presses running at a constant speed. We have only therefore to contend with the need of a great variation of load; and before having experience with them it might be thought this would be somewhat difficult, and that the electrical men would have to be called on to do a good deal of puzzling to get things right. They seem, however, to have done all this naturally, and we can buy motors in the open market that give the tremendous variation required without any trouble at all. It is quite interesting to put a three horse power motor on a press and see the power shoot up to 12 and 15. I have seen it go up even as high as 18 or 20 horse power, at the peak of the curve, for an instant, without hurting the motor, and on a five horse power motor run up to 30 without any trouble at all. The diagram of power is a little peculiar. With a five H. P. motor driving a good sized

punch press about half a horse power is used when the fly-wheel is running loose. The moment the clutch is thrown in there is a very sudden rise until the inertia of the shaft and attached parts is overcome, when the curve falls rapidly to perhaps one horse power or so. If it was not for the heavy ram of the press the line would run along at this, but as the ram goes down, there is, by reason of gravity, a still further decrease of power. When the crank passes the lower center and begins to raise the ram, the load increases but not quite up to the little peak caused by the clutch being thrown in. As the ram gets up towards the top the power dies away, and as the clutch is thrown out it drops down to the original level. All this is when the press is running, doing no work. Ordinarily, when we are doing work, as for instance, punching thick iron, the punch striking its surface when the ram is perhaps half way down, the first quarter of the diagram will be the same as before, but the peak will be very abrupt, rising to a great many horse power. If the punching pressure was uniform as it went through the metal a flat top to the peak would run along for a while, but of course as the punch gets into the metal it has less and less to cut, and the line falls till the wad of metal is loosened, when a sudden drop occurs, a rise of small hight following it as the stripping, or getting the punch out of work takes place. The conditions are different in the drawing press, where the work is struck rather soon after the ram begins to descend; and in drawing a deep shell like a cartridge, or a deep cup, or a seamless can, the power is nearly continuous during the whole stroke, so that the high peak continues straight along in a tableau for a good while and then comes down as the punch is being pulled from the work. For very severe service we have found compound wound motors the best, although we have used the ordinary shunt motor with fairly good success.

MR. TOWNSEND WOLCOTT:—I would like to ask Mr. Smith one question. The diagram represents the power actually taken to do the punching, drawing and so on, but it is not the load thrown on the motor, is it?

MR. SMITH:—Yes, it is thrown on the motor.

MR. WOLCOTT:—Where does the fly-wheel come in?

MR. SMITH:—Sometimes we run presses with but a very small fly-wheel, which stores up but little energy. Of course with a heavy fly-wheel there is more such storage, and the maximum load on the motor is lessened. For this reason we aim to have as heavy fly-wheels as we dare to, but we have to keep them light enough not to break down the presses if crow-bars and such things get accidentally thrown between the dies.

MR. WOLCOTT:—The presses that I have been familiar with, running them with a belt, have a fly-wheel heavy enough to take off a very large portion of that peak; that is, to flatten out the curve a great deal.

Mr. Smith :—Yes, that is true. The fly-wheels we generally use, do flatten out the peak and round off the little humps—so to speak. Of course the peak is much sharper and higher without a fly-wheel. The characteristic form of the curve is the same, however. This is what I attempted to show in my blackboard illustration—without trying to fix any particular amplitude, due to the presence of more or less fly-wheel storage.

Mr. Wolcott :—Another point in regard to one of Mr. Hill's remarks. I find the same thing myself, that manufacturers of machinery, all sorts of machinery, do not know anything about how much power it takes to run it, and sometimes if they do know it, don't want to tell, because they think if they state it takes a certain amount of power it will interfere with the sale; because they think people would be scared by the amount of power it takes. The machinery which Mr. Hill mentioned mostly took less power, some of it took a good deal less than the makers thought. On the other hand I found machinery to take more, in two different cases where I fitted up machinery for mechanical engineers. One was a very well known mechanical engineer. He was very certain he understood the power himself, how much power the machinery took, and he always underestimated it; so that although I put in a great deal more power than he said he wanted, there was only just enough when we got through.

Mr. James Hamblet :—The discussion so far has been almost entirely in reference to the application of individual motors to the machine shop. A little hint was given by one of the speakers in regard to the silk mill. I should like to know if there has been any practice in applying individual motors to the looms in the cotton mills or silk mills, anything of that kind.

Mr. Lozier :—If the question is asked of me, I would say that there have been a number of attempts made to drive these looms by individual motors; some of them I believe have been quite successful, using small motors about $\frac{1}{4}$ horse power, and I understand that there are several large installations in contemplation now which will be operated in that way; but I have no definite information on the subject. The problem seems to be to get a motor that runs sufficiently steady and also to keep the first cost down in comparison with the cost of the loom.

Mr. H. B. Coho :—I would say in connection with the last speaker's remarks regarding silk mill installations, that I have had a little experience with this style of work and am not quite satisfied with the results. The difficulty which we have had seems to have been to get a motor that would start quickly enough to give the proper results on the looms. We are still making tests on this, however, and hope to accomplish it without the use of clutches or anything of that nature.

Mr. Dunn :—About four years ago I equipped some silk

looms with direct-connected motors and the performance was very satisfactory. On account of the steadiness of the working of the motors we were able to increase the picks per minute or the number of times the comb throws back the thread thrown by the shuttle, about 10 per cent, and the freedom from spoiling of silk by waves that will appear if the speed is irregular, was very much greater with direct-connected motors than with belt-driving. The motors were not used by the silk mill for which we made these experiments although we equipped several looms and had them in operation for a number of months. The reason they did not use the motors was because they did not feel there was enough precedent for it. They had a French superintendent who was brought over to establish their works and he was not sure enough of American apparatus to trust it, and then the cost was quite a little above the cost for shafting. On these grounds they ruled the motors out. But the performance of the looms was very satisfactory and much more perfect than with belting. There was not any difficulty of the kind Mr. Coho mentioned in starting quickly enough, since the looms were started by a clutch, and the minute the clutch took hold, the loom went and the motor stood by.

If I may be allowed to make a few comments on some of the other points that have been raised : Mr. Hill said that he believed that there was no limit to the economical subdivision of power. Taking that statement as I believe he meant it, I cannot agree with him, certainly as conditions are at present, and I do not think that they ever will be such that motors will be put upon the smallest tools; the reason Mr. Hill himself pointed out. There are inherent difficulties in the design of very small motors. The regulation is necessarily bad and the cost high, and the facility of control, little. One of the inherent reasons, for instance, why little motors are so, is the fact that for a given volume of copper wire that it is necessary to use in the winding of a certain one-sixth horse power motor that I have in mind, only 38 per cent of that volume is copper; the rest is cotton and wind. This is a condition that will always be with us.

As conditions are at present, I agree with Mr. Smith, although I would put the limit a little smaller than he has put it. I believe it is economical and desirable to-day to put motors directly upon tools for all cases where the motor is one horse power and over. I do not believe in doing it smaller than this, and in a great many cases I do not believe in doing it as small. The standard turning lathe is the most difficult problem to handle, and I would not advise putting one horse power motors to-day on turning lathes. Another point Mr. Smith brought up was the question of the greater amount of light that was obtained when the belts were dispensed with. Just as incidental to that I will mention another fact in connection with the Government Printing Office which I have alluded to before. They keep there

a very accurate record of their sick list. It is such an enormous establishment that this pays. Since the introduction of electric power, the sick list has been reduced 40 per cent. I think that speaks volumes.

Another point in regard to Mr. Leonard's remarks. I am a very strong supporter of Mr. Leonard's methods of control in all of their forms. I believe we have something there that is going to be used more than it is used now, and that it is absolutely the best way of controlling certain kinds of machinery. But I wish I could say that I felt that the method was applicable to a very large class of work that we have to deal with, namely, work involving cutting tools in a machine shop. I do not consider it the best way of controlling such work for this reason: [Making a sketch on the blackboard]. This may represent any kind of machine work. It may represent a large wheel hung horizontally upon a boring mill, or it may represent a large cylinder being turned in a lathe. It has been established that the limit of cutting speed at which we can use this tool is the limit at which the tool will stand up, will not be dulled and will not have its temper drawn by the heat generated. Let us assume that we are surfacing a large circular plate and that we need a cutting speed of 30 feet per minute; now no matter on what diameter we use the tool we want to get a speed of 30 feet, otherwise we are not working our tool up to its full capacity. There will be fewer revolutions per minute the greater the diameter, but the horse power at our cutting tool—the product of the resistance of the tool by the distance over which it cuts—will be constant. Now the consequences are these: When we have large diameters and the speed has to be slow, the torque required to drive goes up. In Mr. Leonard's method of changing the voltage at the brushes of the working motor, which principle applies to all of his methods, this is not accomplished Mr. Leonard's method does not permit the torque of the motor to be increased, although it does accomplish the necessary reduction of speed. Every motor has a certain current capacity. If it is a five horse power motor on 110 volts, 40 amperes is its current capacity, and at that load it is giving the maximum torque for which it is designed and which it will run well under. Now when we reduce the speed of the motor down to say a quarter of its natural speed, in order to make this big piece of work revolve very slowly in order not to make the cutting speed too high, we cannot increase the current and consequently the torque of the armature in proportion as we reduce the speed. This problem is one that I have worked over a great deal and the only satisfactory solution that I can see is: Let us use Mr. Leonard's methods of regulation for certain ranges of speed to get that even gradation that I have mentioned, but for the large ranges of speed use a nest of gears, the principle of which may be illustrated by this: Here we have a pinion, there a gear.

There we have another pinion and here a gear out of mesh with it. Now the motor is connected to one of these shafts and the work to the other. If we wish a high speed and a small torque we leave this connection on. If we wish a large torque and a low speed we throw this gear into mesh with this one and the other out. In that way the motor always runs at its constant speed and therefore is capable of giving the constant horse power which the tool consumes but the revolutions per minute and torque at the work is varied. We have the tool consuming a constant horse power no matter what the speed of the work, and the motor giving a constant horse power. and this seems to me to be the only proper solution for this question. You may obtain these speeds of course in some other mechanical way; but my point is that I believe they must be obtained mechanically, and not by electrically regulating the motor.

Mr. Leonard:—The point that Mr. Dunn makes is one that I have understood perfectly clearly since the beginning of my work in this direction, and it was about nine years ago that the matter was thoroughly threshed out in connection with the operation of a large lathe requiring about 10 horse power in the shop of William Sellers & Co., and I agree with Mr. Dunn in the statement that for the problem as he states it there, mechanical reductions and transformations of a constant power are the only solution, and that you cannot make use of electrical transformations except at greater first cost so long as copper wire gets hotter when the current increases, which is likely to continue. Of course if the motor be made so large as to have a sufficient torque to correspond with the largest torque and slowest speed of your lathe, the same motor will operate perfectly through the entire range. But when you buy the cheapest motor you can buy for that lathe, at its highest speed, it won't be big enough to carry the torque that is necessary for the slowest speed. Personally I have found, and various licensees of mine have found, that a combination of the two makes a very good arrangement; that is: to get wide ranges by means of a few mechanical gears and intermediate gradation that may be required for a great many classes of work by means of the electric regulation.

Mr. Lozier:—I should like to ask Mr. Dunn if it is possible to turn down a large cylinder or to face off a large casting by the method shown: at least, how does he expect to change his gears while the tool is in operation.

Mr. Dunn:—Mr. Lozier has me there. I do not limit myself just to gears; but I said mechanical reduction. You might use, if you would, the Evans Reduction Cone which you are undoubtedly familiar with. I have never had much experience with this cone [making a sketch on the blackboard.] But where I have used it it has not been altogether satisfactory. That is a piece of leather belt. These are friction cones, and this is the driving shaft. If the belt is going over there you get

a high speed. If you get the belt so that its running point is here you get a low speed and great torque. You accomplish the same effect that you do with the gears, with no jerks, no intermediate points.

Mr. Oberlin Smith :—Such an arrangement of gearing can be worked by letting the gears stay in mesh and run loose on the shaft with a series of jaw clutches or friction clutches, contrived to put in action any desired pair; but of course all that makes a good deal of complication. A good mechanical device of this sort has still got to be "threshed out" from somebody's brain fibre.

A question was asked about motors for textile work. I have not had experience with looms, but it may be a matter of interest that some years ago certain clients of mine got me to look into the matter of running every individual spindle of a spinning frame, where there were several hundred, set in a row, running at a speed of 10,000 revolutions a minute, and taking a very small fraction of a horse power each. The parties were among the largest and the richest men in that industry in this country. They were well-known as men who made enormous quantities of spindles and they thought there might be something in the scheme. I then went far enough (with some model spindles that they sent me and some little extemporized motors which were not very efficient) to make up my mind that there was not "anything in it." Such an arrangement is the very extreme ideal application of individual motor driving, I should think. I do not know of any condition in the world, in practical machinery, where we could well divide up a current into more small pieces. If it is ever done it will certainly show that individual motors can be put almost anywhere. I am not perfectly sure myself but what it will be done yet. You all know that in a spinning frame a big tin-plate cylinder or drum runs the whole length and acts as a driving pulley. Each spindle has on it a small grooved pulley called a "whirl" about an inch in diameter. Each belt is nothing but a piece of cotton string tied in a knot. Those knots seem to be a very crude device. It is not practicable to splice the strings, and as some get looser than others they do not give perfectly uniform results in the matter of speed. Not only is there difficulty in keeping this long row of little cotton belts tight alike, but they cannot be adjusted to a general proper tightness to get the best effect without wasting a good deal of power.

This is therefore a case where it is very desirable that we should do away with the drums and all their journals and the air resistance and journal friction, etc.,—as also all those miserable cotton belts, which waste a great deal of power themselves. It doubtless would be very desirable to run these spindles with individual motors, but that is a problem for the electricians to work on. It looks impracticable now, but there may be such

radical improvements made, some day, in motors that we may come to an application of this sort.

Mr. Douglass Burnett :—The remarks of the last speaker remind me that a limitation to the use of direct-connected motors is in respect to high speed. On several occasions the proposition has been presented to me ;—Can a direct-connected motor be adapted to centrifugal cream separating or clothes drying machines? As these run at speeds of ten thousand or so turns a minute, I think there would be some difficulty in designing direct-connected motors for them. I should like, also, to refer to the remarks of several speakers, and by combining them, point out that the use of direct-connected motors is limited by the commercial difficulty of having to convince several people as to their advantages and economy. We electrical people believe in them, but then there is, first, the power user who must have a reliable motor and a reliable source of power. The remarks of Mr. Coho indicate that as it is not advisable, for security's sake to run a whole line of shafting and a number of machines from one motor, therefore it is not advisable to use an insecure source of power such as a single dynamo or a single supply service when the current is purchased. The man who can furnish an isolated plant that gives reliable power, or the central station man who can give uninterrupted service through twenty-four hours a day, is going to satisfy, in at least one way, the man who is to buy the motors. I find that electric motors are largely used for coffee roasting for the reason that a reliable source of power is available, as any interruption of the current would very seriously jeopardize the value of a large amount of material. Then too we must get the power user to know, or be able to estimate closely, the amount of power really required and used. They frequently say,—I have five horse power running ten hours a day,—and you will estimate on that basis as to what the cost of the power would be; then when you take other instances where the same size of motor is in similar use,—you find that the cost of power is perhaps one-third or one-half of your previous estimate. In other words, people have excessive ideas as to the amount of power they require, and we should have some way of reducing those ideas; for instance, by seeing that the makers of machines and tools, the makers of planers, drills, printing presses, etc., know the power required by the machines they sell. I have known very few machine builders, in my own experience, to give to users and buyers of their tools any estimate of the amount of power required. I do know that makers of apparatus for coffee roasting and handling do give estimates, and they are the only people who do that. It seems to me that one good way to secure a larger use of electric motors generally, and particularly direct-connected motors, would be to convince not only the owner directly but also the makers of the tools, as to the economy and other great advantages of their use.

Another man to convince is the laborer—the man at the machine. That they appreciate the motors is, I think, very clearly shown by Mr. Dunn's statement that the sick list at the Government Printing Office was reduced by forty per cent. It is also clearly shown by Mr. Hill's remarks on the unsatisfactory results secured by certain motors at the American Book Company. Now I think you will at once grant that if the man who uses the machine– the laborer—can be convinced that the direct-connected motor is the best thing for him to use, we have an important helper.

To summarize—as I said at the beginning, we electrical people are in favor of all electric motors; but we must convince three people of their advantages—the owner of the works, the laborer, and the maker of tools. I think that we need bear this in mind in all our dealings in connection with the subject.

Mr. Oberlin Smith:—I should like to hear from some of my electrical friends who understand designing motors as to what the limitations of speed are; why a motor cannot be made to run 10,000, just as well as any other speed—if we keep within the limits of damage by centrifugal force.

In regard to possible spindle motors; of course they must be without commutators—probably induction motors with two or three-phase alternating currents. I do not myself know any absolute bar to motors excepting their high cost and possibly the weight, too great weight of the armatures. If that could be reduced so as not to be objectionable it seems to me the only real reason against them, is the cost, which probably might always be prohibitory—but who knows?

Mr. Arthur Williams:—Referring to the use of direct-connected motors on small machines, I might mention that a short time ago we heard of the experimental application of three-phase motors to the spindles of a mill in Scotland with satisfactory results Very high speeds are obtainable and that system permits the necessary instantaneous stoppage and reversal of the machines. We saw, also, while in Berlin last summer, a buzz-saw having a speed of about 4,000 revolutions a minute, driven by an armature directly attached to a short extension of the shaft on which the saw revolved. A planer received its power in the same manner, and all of the wood-working machines of the shop were operated by motors directly attached to their parts. The enormous works of the Allgemeine company of Berlin are equipped entirely with direct-connected machines and tools. The flexibility of this system permits the most convenient and efficient arrangement of the machines; every part of the floor, there being neither shafts nor belts to obstruct the vision, is directly within range of the superintendent's office, and the conditions otherwise are most conductive to health, cleanliness and the comfort of the employees. The power supply is one of the smallest items of shop expense,

while labor is one of the largest, and anything that increases the efficiency, or reduces the cost of labor, is worthy the most careful consideration.

The New York Edison company, feeling that this subject should be brought before the public, its users of power, is arranging to issue a second circular, written by Mr. Powers, who is considered one of the best advertising writers in the country. Illustrating what I mean between the difference in a saving in the cost of power, the small expense, and of labor, the large expense, I might mention an incident that occurred in the experience of Mr. Powers, of which he told me. He was writing for one of the oil companies, the manager of which to that time had simply emphasized the saving in the annual oil bills resulting from use of his oil. Mr. Powers recognized that this was a pretty small item and felt that alone it did not justify the same attention from the busy man at the top that the oil man perhaps thought it should have; he wondered whether the oil, being of higher efficiency, did not also save largely on fuel, depreciation, repairs, etc., and he found it did. In one instance, on one of the large railroad systems of England, where first tried experimentally, the saving in fuel, as one of the items, was so considerable that the allowed engine supply of coal could not be consumed, and I think this item alone came to more than the entire cost of oil.

We had a customer here who in order to meet a sudden demand for his goods was compelled to consider the rental of three additional lofts giving each a complete equipment of sewing machines—previously a single floor, with foot power, being sufficient. He was advised to try an electric motor, being assured that with steadiness of operation and higher speed the output would be largely increased, and this was true to such an extent that the addition of the motor gave the plant sufficient capacity for all requirements and no further changes required. The electric power cost about $40 a month,—less than a single operator received.

But to get back to the point I really want to emphasize: There are several large firms or corporations in Europe devoting themselves entirely to the manufacture of combined machine tools and motors, with the result that this complete apparatus is quickly available. Since our return we have been impressed by what seems a lack of co-operation between the motor and the tool manufacturers, making it possible to secure such apparatus, if at all,only after considerable delay. This was our own recent experience in purchasing some lathes and pipe cutters with motors directly attached. All desire of course that every branch of our profession shall be brought to the highest state of efficiency, and it seems that here is a great opportunity, but the manufacturers must get together. If they do not, the tool makers will be forced to manufacture motors, or the motor manufacturers to make tools.

As to the saving to the user, there seems no possible room for doubt. We are recommending generally the adoption of direct connected motors, but have not as yet quite decided as to how far down we should go in regard to size. It would seem economical to put a motor, directly attached, on any machine requiring more than one-half H. P., and on printing presses and paper cutters and any other machinery using intermittent service. The desirability of attaching motors to sewing machines and the like is probably questionable, as the labor necessary for their maintenance must increase, and this might become a very important item of expense. For a number of sewing or other small machines some subdivision is undoubtedly desirable and economical, as every factory has its dull seasons and the discontinuance of sections at such times would undoubtedly result in considerable saving.

Perhaps the advantages of the direct application of power are nowhere shown so much as in electric elevators. About 14,000 H. P. are now supplied in New York at an annual cost of approximately $18 per H. P. installed; the car mile costs vary from 14c. to 18c., in comparison with from 36c. in winter to 50c. or 60c. in summer as fair average costs of the hydraulic system. I speak only of the system which employs an electric motor directly driving the winding drum or screw, and not the electric pumping system, which continues in the hydraulic link all of the disadvantages of that system, other than the continuous supply of the central station, without any saving in the costs.

Permit me, Mr. President, to again emphasize the need which seems to exist in New York of that greater co-operation between manufacturers of motors and of machine tools.

Mr. George Hill:—I think it is generally the fact that in any given plant the engine which will be placed in connection with the dynamo will be a higher grade engine, more economical in its water consumption and better able to do the work and give a longer life than the engine which is ordinarily placed in connection with the shafting or belting. So far as my experience goes there is no comparison at all between the cost of maintenance of an electrically operated plant and a belt-driven plant, the belt-driven plant costing so very much more.

In regard to the illustration which I gave of the American Book Company in regard to the Smyth sewing machine, there was both satisfaction and dissatisfaction. In regard to the presses we found some of the operators intent on wrecking the machine. One of them I had to argue with forcibly to stop it. In regard to certain of the other machines, and some of the more intricate machines, we found the operators not only understood, but were very much in love with them. One of their most expensive machines stayed idle for three months until the man that was intended to operate it was discharged and a new man put in. Every time the old man undertook to run the machine

he tried to wreck it and there was no arguing with him, no way of persuading him to operate that machine properly. After he was discharged there was no trouble. That comes back to the personal equation which exists in every plant.

Very few engineers realize the enormous percentage of loss in the transmission of relatively small powers by belting, due to excessive friction in bearings caused by having the belts too tight. As an illustration I had recently in one of our power buildings, where each one of the tenants is metered, one who had a five horse power motor belted up to a single shaft which ran down through the center of the floor operating his various machines, and his current bill showed that he was using 40 horse power hours a day right along. His machines evidently did not require anything like so much power, so he disputed the bill. I put an ammeter on the motor circuit and measured the power consumption throughout the various transformations, and found that the work was the smallest item—I think about three-quarters of a horse power; all the rest was due to stupid connecting up. His belts were so tight that by slacking the motor back on the stand a little and decreasing the belt tension we took off one horse power. Those are things which are personal, which are not inherent in the machine at all, and unless looked for and guarded against will interfere with good results. It may be said that they are inherent in any belting work since in all such work nobody knows the amount of power that is being consumed, nor can anyone make any proper estimate of it from looking over the shop, and it is only when we use a motor and an ammeter in the motor circuit that we actually know what we are doing.

Mr. Jesse M. Smith:—It seems to me that the key note of this whole question of electric transmission is that the electric motor is more convenient, more flexible and more directly applicable than any other form of power transmission. The question of economy in friction between the cylinder of the slow speed Corliss engine and the tools that are driven at the other end, whether by shafting or by electrical transmission, is a mere trifle in favor of electricity; it may amount to 3, 4, 10 per cent., but rarely more than 10 per cent. From the point of view of saving in friction, there is nothing in it; that is when all the tools are in operation. In scarcely any factory, (not even a textile factory, and certainly not in any machine shop,) are one-third of the tools in operation at any one time. It may seem extraordinary to make the statement that in a textile factory for instance there is a loss of time at the machines, but such a loss exists, and the economy of electric transmission is due to the motors being stopped when the machines stop. Where line shafting is used it has to be running all the time; it has to be made strong enough to supply the maximum demand but generally supplies much less. I had occasion only recently to go over the question of transmission in a very large manufacturing establishment

where the buildings were scattered over a large territory, and where the machines were driven by line shafting and belting. The question was whether it was desirable to throw out the shafting and belts and go to electric transmission. I figured it over quite carefully and found a saving of just about 10 per cent. in the amount of friction. The parties told me that nearly all the tools ran constantly, that the line shafts must always be running and that the tools themselves, while not all being constantly in use, must be always ready for use. The question of electric transmission in this case, so far as the saving in friction was concerned, was practically not worth the expense of the change. The whole question comes back, as I said before, to the convenience and elasticity of electric transmission, and my idea is that an individual electric motor should be placed on every machine. The limit to which it can be carried downward, is simply a question of dollars and cents—how cheap a motor can you get to do the work? As the gentleman who last spoke said, there is a difference between the machine builder and the motor builder;—they must get together, and if they do not get together there will be trouble. The machine builders are already beginning to build motors. My idea is, that very soon every company building machine tools will build its electric motors in its own factory, and will build them as simply and as cheaply as it now builds machine tools. When that time comes, we will see the smaller tools supplied with smaller motors, and there is no telling where the limit may be. We may even see Mr. Oberlin Smith's idea realized,—each individual spindle moved by an electric motor. Mr. Smith touched upon a very important point which I should like to see brought out more fully. We have not heard to-night whether the current for these motors is direct or alternating. Alternating seems to be the craze just now, and if there is anybody that knows anything about alternating motors—I do not—I would like to hear something about them.

Mr. Oberlin Smith:—My experience with driving presses, etc., has usually been with a direct current—110 volts and 220 volts, so far. I think one reason for the prejudice, if there be such, against alternating currents is on the same order as the feeling that one must not "monkey with a buzz saw;" people do not want to handle the high potential alternating currents usually found on the market.

Mr. Williams:—Mr. President, would you allow an additional word as to losses? As I left the office this afternoon, one of our engineers handed me a statement as to losses on shafting running on the local system. The percentages vary as follows: 43%, 23%, 21%, 43%, 68%, 61%, 27%, 29%, 35%, 22%, 66%, 41%, 52%, 37%, 29%, 18%. We have found shaft loss variations from 5% to 70%, and in some instances still higher.

The President:—How are those measured, Mr. Williams? Is that with a full load on—all the tools working?

Mr. Williams:—At maximum and average load; these figures show the shaft losses on average loads.

Mr. George Hill:—While we are on that point I wish to state that I have taken a great many indicator cards from engines under ordinary working conditions, taking not a single card but continuous cards, running over a period of from a couple of hours to three or four days, and then afterwards I have indicated the engines when the shaft and transmitting belting alone was on and the work all thrown off, and I have never found a case in which the friction losses were less than 50 per cent. of the average load, and I should not believe, unless it was backed up by voluminous figures, that there are any cases of any size in which the shaft losses were as low as 10 per cent. of the average load. I should want to see the most careful and complete figures and know all of the facts bearing on them. I have a great many observations given to me by my friends of similar plants, and I find in no case does the loss drop below 30 per cent. except here and there, in isolated cases, where there are special conditions, and in ordinary practice such as we meet here in New York in buildings, the losses are certainly very much greater than 30 per cent. In regard to a high speed motor I would like to state that I have seen a generator which was designed to run at 5,000 revolutions per minute, and almost the heaviest parts of that generator were the two rings which were used to keep the commutator bars on. The commutator was about four inches in diameter and these rings, as I recall them, were about four inches internal diameter and five and one-half inches external diameter and about three-quarters of an inch thick.

Mr. Hamblet:—Mr. President, I have been much interested in this discussion, and I have an idea that many of the gentlemen present feel as I do, and that is that they would like to hear an expression from yourself, sir, in regard to the discussion.

The President:—The subject under dicussion is of great importance not only to ourselves as a body, but to the manufacturing community at large. The position of the United States among the nations of the world as a manufacturing country depends upon the mechanical facilities possessed for manufacturing on a large scale, and upon the average intelligence of the workman to avail himself of those facilities. For this reason, all that facilitates and accelerates the operations of tools is directly advantageous to manufacturing and commercial ascendency. Just as in other departments of electrical applications, it is not merely the saving in first cost which is effected by electrical methods of distribution, but the pliability and convenience of electric methods which has won for them success. It is the ease of control of an electric motor, its handiness, convenience and the flexibility of the wire or wires which supply it, that makes the electric subdivision of power so valuable an adjunct

in manufactories, and it may well happen, as has been pointed out this evening, that where there is no seeming advantage in economy by the subdivision of electric motive power, a great advantage may accrue in convenience and facility of operation, and the increased output thereby promoted.

[Adjourned.]

DIED.

SHEBLE :—At Philadelphia, April 20th, 1899, Franklin Sheble, late of the firm of Sheble and Patton, of Philadelphia, and representative of the Stanley Electric Company, at 71 Broadway, New York. Mr. Sheble was born in Philadelphia, April 10th, 1866, and was educated at the Philadelphia Central High School, the University of Pennsylvania and Cornell University. After about six years experience with the General Electric Company, at Lynn and Schenectady, he formed a partnership with Mr. Price I. Patton, as electrical engineer and contractor, and was more recently identified with the Stanley Electric Co., at the New York office. Mr. Sheble was elected an associate member of the INSTITUTE October 21st, 1890, and transferred to membership December 18th, 1895.

AMERICAN INSTITUTE OF ELECTRICAL ENGINEERS.

New York, May 16th, 1899.

The Sixteenth Annual Meeting of the Institute was held this date at 12 West 31st St., and was called to order by President Kennelly, at 8.10 P. M.

The President:—The Secretary will read the announcements.

The Secretary:—At the meeting of the Executive Committee this afternoon, the following Associate Members were elected.

Bogen, Louis E.	Instructor in Physics, University of Cincinnati; residence, 547 Hale Ave., Avondale. Cincinnati, O.	Thos. French, Jr. H. S. Rodgers. T. J. Creaghead.
Bonynge, Paul	Attorney and Counsellor at Law with Almet R. Latson; residence, 104 Berkeley Place, B'klyn, N.Y.	Sam'l Sheldon. A. W. Berresford. Aug. Treadwell, Jr
Bowman, Joseph H.	Material Agent, Ferrocarril de Chia. al Pac. Chihuahua, Mexico.	Louis Duncan. H. S. Hering. R. W. Pope.
Brown, Ellis Eugene	Electrician Mining Dep't. Del. Lack. & Wn. R. R., Kingston, Pa.	H. B. Smith. H. J. Ryan. W. E. Goldsborough.
Chappell, Walter E.	Electrician, on U. S. S. Chicago, U. S. Navy, Washington, D. C.; residence, Barnesville, O.	Townsend Wolcott. J. Martin. F. C. Caldwell.
Herdt, Louis A.	Lecturer in Electrical Engineering McGill University, Montreal, Canada.	R. B. Owens. A. E. Kennelly. R. W. Pope.
Johnson, Albert C.	Superintendent and Electrician, Electric Light & Water Works, Box 7, Willmar, Minn.	H. C. Eddy, R. W. Pope. W. J. Hammer.
Johnston, Thos. J.	Counsel in Patent Matters, General Electric Co., Schenectady, N. Y.	Elihu Thomson. C. P. Steinmetz. E. M. Hewlett.
Kelly, John F.	The Stanley Electric Co., Pittsfield, Mass.	E. J. Houston, R. W. Pope. A. E. Kennelly.

Knox, Chas. Edwin	With C. O. Mailloux, Consulting Electrical Engineer, 150 Nassau St.; residence 108 W. 122nd St., New York, N. Y.	C. O. Mailloux. W. D. Weaver. Gano S. Dunn.
Macartney John F.	Managing Director, Macartney, McElroy & Co. L't'd. 53 Victoria St., London, Eng.	C. G. Goldmark. Frank Bourne. E. T. Birdsall.
McCarter, Robert D. Jr.	Electrical Engineer, The General Electric Co., 205 Union Street, Schenectady, N. Y.	C. P. Steinmetz. E. J. Berg. Eskil Berg.
McClenathen, Robert	Division Superintendent, Electric Train Bulletin Co., Box 476 Ithaca, N. Y.	Edw. L. Nichols. Fred'k. Bedell. Ernest Merritt.
Middleton, A. Center	Electrical Tester, General Electric Co., Box 253 Schenectady, N. Y.	S. Dana Greene. A. L. Rohrer. Gano S. Dunn.
Mullin, E. H.	General Electric Co., 44 Broad St.; residence, 188 Columbus Ave., New York.	Thos. A. Edison. S. Dana Greene. T. C. Martin.
Ramsey, Harry Nathan	Wire Chief, 79th St. and Columbus Exchanges, New York Telephone Co.; residence, 1062 Lexington Ave, New York City.	U. N. Bethell. H. J. Ryan. Fred'k. Bedell.
Robinson, Geo. P.	Special Agent, The Wisconsin Telephone Co., Milwaukee, Wis.	C. F. Burgess. D. C. Jackson. M. C. Beebe.
Schoolfield, Frank Robert	Draughtsman, Hodges & Harrington, 60 State St., Boston; residence, 10 Clifton St., West Somerville, Mass.	Chas. K. Stearns. Edw. C. Clement. C. B. Graves.
Sturdevant, Chas. Ralph	Assistant Professor of Electrical Engineering, Kentucky State College, Lexington, Ky.	C. S. Reno. H. H. Hornsby. W. E. Goldsborough
Whiting, S. E.	Assistant in Electrical Dep't. Harvard University; residence, 11 Ware St., Cambridge, Mass.	C. A. Adams, Jr. Gifford LeClear. R. W. Pope.

Total 20.

The following associate members were transferred to full membership:

Approved by Board of Examiners, April 13th, 1899.

Lardner, Henry Ackley	Borough of Manhattan Electric Co., 33 Gold St., New York City.
Kennelly, Arthur E.	Electrical Engineer, Firm of Houston & Kennelly, Philadelphia.

The Volta Centenary.

The President:—Before taking up the business of the evening, I crave your attention for a few moments upon a somewhat different topic. Amid the rapid development of electrical engineering sciences and the kindred arts, which are becoming more potent and useful every day, it is occasionally desirable to stop and look backward for the purpose of tracing the distance which has already been traversed and for the purpose of marking and counting the difficulties that have been passed. Such a retrospect fills one with gratitude to the past, and with confidence for the future. A very notable century mark was passed just one hundred years ago by the discovery of the chemical source of electric energy by Alessandro Volta, professor of physics in the University of Pavia. That discovery was the result of a long series of researches made by Volta in the unwavering belief of his guiding principle that electrification attended the contact of dissimilar materials, and that proposition, under some limitation, has withstood every assault which during a century has been brought against it. Volta did more. He gave to us the first plate condenser, the first absolute electrometer and the first electrophorus; but the column upon which his fame must principally rest is the bimetallic pile first erected by his own hands—the voltaic pile which made the electric telegraph first possible. Napoleon Bonaparte, ever keen to recognize greatness in the great, marked him with favor and regard, and Volta lived long to fill the full measure of a great and noble life. We understand that but yesterday an exhibition opened at his birthplace at Como, on the shore of the beautiful lake of that name, to commemorate the centennial anniversary of that discovery, to place a wreath upon the pedestal of his statue and to mark a wide world's recognition of a world-wide renown. This Institute has taken no formal part in those proceedings; but as long as we have volts impressed upon our circuits, so long shall we testify to our recognition of Volta's fame in our language, in our thoughts and in our work.

The President appointed Ralph W. Pope and A. A. Knudson tellers, and they proceeded to count the ballots sent in by the members.

The following annual reports of the Council and Treasurer were submitted and received.

AMERICAN INSTITUTE OF ELECTRICAL ENGINEERS.

Report of Council for the Year Ending April 29th, 1899.

New York, May 16, 1899.

As required by the Constitution, the Council submits herewith for the information of the membership a report of its work, also its financial standing at the close of the fiscal year, April 29th, 1899.

Two meetings of Council, and ten of the Executive Committee have been held, one during each calendar month.

The work of the Committee on Standardization was sufficiently advanced early in the year to permit of the printing of a preliminary report in the May issue of the Transactions. and it was brought before the General Meeting at Omaha for discussion. Owing to the unfortunate loss of the stenographer's notes, it became impossible to reproduce the discussion, but the work of revision has been faithfully pursued by the Committee, and it is now practically completed, although not in time to be incorporated in the annual volume for 1898.

In his inaugural address at the Omaha meeting, the President outlined a plan, by which the Institute might secure the co-operation of the various college laboratories throughout the country in pursuing a systematic course of electrical research. To further this work, the Council made an appropriation of $50, and the following committee was appointed to prepare suggestions:

DR. A. E. KENNELLY, Chairman.

Prof. W. A. ANTHONY,	Dr. SAMUEL SHELDON,
Dr. FRANCIS B. CROCKER,	CHAS. P. STEINMETZ,
Dr. CARY T. HUTCHINSON,	Prof. ELIHU THOMSON.

This committee in November last prepared a circular which was sent to all electrical engineering departments of American colleges; submitting the following list of proposed investigations.

(1) The effect of sustained high temperature upon the insulation resistance of dielectrics.

(2) The influence of sustained high temperature upon the dielectric strength of insulating materials.

(3) The influence of sustained high temperature upon the hysteretic coefficient of commercial iron.

(4) The influence of chemical impurities in iron or steel, upon the hysteretic coefficient

(5) The hysteretic coefficient of magnetic alloys.

(6) The temperature coefficient of resistivity in commercial copper wires.

(7) The temperature coefficient of resistivity in commercial aluminium wire.

(8) The temperature coefficient of resistivity in alloys commercially employed. (It is desirable to include analysis of the alloys tested as well as their physical properties).

(9) The highest conductivity obtainable in copper wire at any standard temperature.

(10) The highest conductivity obtainable in aluminium wires at any standard temperature

(11) The analysis of dielectric losses between parallel copper wires maintained at high E. M. F.; (1) alternating and (2) continuous, into component parts, such as chemical, electrical and mechanical.

(12) The influence of wave form of alternating E. M. F. upon the dielectric strength of dielectrics.

(13) The influence of wave form of alternating E. M. F. upon the sparking distance between needle points in air.

(14) The influence of the room temperature upon the temperature elevation of dynamo machines under a given load, as computed from their increase in resistance under load. (Sec. 32. Preliminary Report of Standardizing Committee to AMER. INSTITUTE OF ELEC ENGRS. June, 1898.)

(15) The distribution of temperature elevation in field coils of dynamo machines as dependent upon their form and dimensions.

(16) The relations between the "load loss" and "short-circuit core loss" of an alternator. (This has reference to Par. 16d, A. I. E. E. Preliminary Report on Standardization, June, 1898).

(17) The counter-E. M. F. of electrolytic deposition cells at potential differences ranging between the maximum polarization voltage and zero.

(18) The seat of the increased counter E. M. F. in storage cells during rapid discharge.

(19) The magnetic properties of alloys containing iron, nickel and cobalt.

(20) The magnetic retentivity of powerfully twisted iron and steel wires, or of magnets composed of such twisted wires.

(21) The permeability of magnetic materials at low values of magnetizing force.

(22) The dielectric strength of different substances employed for insulating at different frequencies of alternation.

(23) The influence of very high frequencies of alternation upon the sparking distance between needle points in air. (The highest attainable frequencies preferred)

(24) The dielectric strength of vapors of different substances.

(25) Influence of wave form upon efficiency of converters. (The so-called rotary converters).

(26) The influence of magnetic field upon electrolytically deposited bismuth.

(27) The conditions giving rise to sparking at commutators.

Of these subjects, the following numbers have been taken up at different colleges:—Nos. 1, 2, 3, 4 5, 7, 12, 13, 14, 15, 16, 17, 18, 19, 20, 21, 22, 25, 26, and 27. The plan has met with the general approval of those members of the INSTITUTE who are in charge of electrical laboratories in universities and colleges.

It is hoped that members of the INSTITUTE encountering problems in practical work which are worthy of investigation, but for which they have neither time nor facilities, will submit additional problems which will increase the importance of this work.

At a meeting of the committee of the National Board of Fire Underwriters at Chicago, January 9th, the INSTITUTE was represented by Richard H. Pierce of Chicago.

In view of the accumulating balance in the bank account at the Mercantile Bank, and the fact that a charge is now made for the collection of a large proportion of out-of-town checks, the Council has authorized the establishment of a reserve fund in an approved Trust Company which will draw two per cent interest. A sufficient income will, it is believed be realized to cover the extra cost of collection of checks, especially as the rule of the banks has been somewhat modified

Owing to the removal of Prof. W. M. Stine, Local Honorary Secretary from Chicago, it became necessary to appoint a successor, and as Mr. R. H. Pierce of that city appeared to be the choice of the larger portion of the members he was appointed accordingly.

The Council has named the following local honorary secretaries in addition to previous appointments.

H. F. PARSHALL, London, for Great Britain.
JAS. S. FITZMAURICE, Sydney, for Australasia.
PROF. ROBERT B. OWENS, Montreal, for Dominion of Canada.

At the meeting of Council, March 22d, it was voted that the next General Meeting of the INSTITUTE be held at Boston Mass.

The total membership at the close of last year's report was 1098, classified as follows:

Honorary Members	2
Members	352
Associate Members	744
Total	1098
Restored to Membership	1
Associate Members elected May 1st, 1898, to April 29th, 1899	103
" " " previous year and since qualified	10
Total	1212

Resignations have been received during the year and accepted from the following in good standing:

MEMBERS:

JAMES D. BISHOP, FRED. A. BOWMAN, EDWARD D. BROWN, JOHN E. DAVIES, AUGUSTINE R. EVEREST. CHARLES WIRT.

ASSOCIATE MEMBERS:

WM. J. A. BLISS, DAVID I. CARSON, J. W. CREWS, DARRAGH DELANCEY, KARL LENZ, JOSEPH T. MONELL, CHARLES T. MOSMAN, ALBERT L. PARCELLE, LOUIS C. RALSTON, JOHN C. SHEDD, EDWARD A. WAGNER, H. FRANKLIN WATTS, GEORGE E. WENDLE.

Total Resignations 19.

There have been the following deaths during the year:

MEMBERS:

CHARLES E. EMERY, FRANKLIN SHEBLE,

ASSOCIATE MEMBERS.

CLARENCE G. DAVENPORT, CLARENCE P. GOTT, FREDERICK H. SMITH.

Total deaths	5	
Dropped as delinquent	39	
Elected but not yet qualified	16	79
		1133

Leaving a total membership of 1133 on April 29th, (a net gain of 35), classified as follows:

Honorary Members	2
Members	363
Associate Members	768
	1133

A list of the members elected during the year accompanies this report. The names have already appeared in the TRANSACTIONS.

The reports of the Secretary and of the Treasurer show in detail the financial standing of the INSTITUTE at the close of the fiscal year, together with an itemized statement of receipts and disbursements during the entire year:

SECRETARY'S BALANCE SHEET

For the Fiscal Year Ending April 29, 1899.

Dr.		*Cr.*	
Balance from previous year	$ 221 40	By cash to Treasurer............	$11,075.00
Receipts for the year	11,487.96	Cash on hand.................. ...	634.36
	$11,709.36		$11,709.36

ITEMIZED STATEMENT OF RECEIPTS AND DISBURSEMENTS OF THE INSTITUTE.

For Fiscal Year Ending April 29, 1899.

General Account.

Receipts.		*Disbursements.*	
Treasurer's balance from previous year	$1,453 09	Revenue Tax........................	$24 00
Secretary's " " " "	221 40	Bank Exchange................ .. .	56
Entrance Fees......................	480 00	Miscel aneous...............	12 60
Life Membership fees (W. F. B. Roquette, S. E. Doane, H. Ward Leonard)...........	300 00	Chicago Meetings...........	19 00
Past Dues.................	962 01	Library............	2 50
Current Dues........................	8,590 91	Ice................................	26 55
Advance Dues.......................	85 00	Laundry..	9 00
Stenography and Typewriting.......	20 67	Office Expenses....................	28 18
Transactions Sold..................	583 67	" Fixtures.....	95 53
Transactions Subscriptions..........	264 25	Express............................	170 50
Advertising..............	135 50	Telegrams............	6 82
Received for Binding...............	41 00	Stenography and Typewriting.......	734 25
" " Congress Book.........	22 95	Stationery and Miscellaneous Printing	329 39
" " Reprints Vol. 4....	2 00	Postage............................	450 87
		Messenger Service..................	6 25
		Salary Account.....................	2,500 00
		Meeting Expenses......	188 40
		Rent Office and Auditorium.........	1,125 00
		Engraving and Electrotyping	431 38
		Binding..............	231 07
		Publishing Transactions............	2,655 38
		Co-operative Research..............	8 90
		Engrossing	7 50
		Compounded Membership Fund.....	800 00
		Secretary's Balance to next year.....	634 36
		Treasurer's Balance to next year.....	2,664 46
	$13,162 45	Total,	$13,162 45

Commercial Department.

Dr.		*Cr.*	
To balance from previous year......	$185.50	Paid for Badges, back volumes, etc..	$293.06
Sales to May 1st	517.33	" " Engraving Names....	19.48
		Badges on Hand.......	85.00
		Bills Receivable....................	16.00
		Cash on Hand...	289.29
	$702.83		$702.83

All outstanding bills against the Institute were paid in full, April 27th.

There is due the Institute and probably collectible $805.00

The amounts mentioned as probably collectible in the last two annual reports have been verified by the results, and during the past year the amount collected exceeded the estimate by $202. The total receipts for the past year exceeded the previous year by $2,460.95, while the expenses were $27.05 more, showing a net financial gain of $2,433.90, of which $800 was transferred to the compounded membership fund.

Property on hand according to inventory, May 1, 1899.

Office Furniture and Fittings	$ 348.05
Catalogue Type, Cases, etc.	210.41
Transactions on hand.	3,253.00
Congress Books	666.00
Library	200.00
	$4,677.46

TOTAL NET ASSETS.

Treasurer's total Cash Balance	$5,068.38
Secretary's " "	634.36
Commercial Fund Stock and Cash	390 29
Property as per Inventory	4,677.46
	$10,770.49

Respectfully submitted for the Council,

RALPH W. POPE,

Secretary.

TREASURER'S REPORT.

FROM APRIL 30, 1898, TO MAY 1, 1899.

GEORGE A. HAMILTON, TREASURER, in account with

AMERICAN INSTITUTE OF ELECTRICAL ENGINEERS.

Dr.

Balance from April 30, 1898	$ 1,453 09	
Received from Secretary, April 30, 1898, to May 1, 1899	11,075 00	$12,528 09

Cr.

Payments from May 1, 1898, on warrants from Secretary as approved by Council or Executive Committee, Nos. 997 to 1,104 inclusive	$9.863 63	
Balance to new account	2,664 46	$12,528 09

BUILDING FUND.
(Mercantile Trust Co.)

Balance as per last report	$850 00	
Interest accrued to May 1, 1899	140 48	$990 48

COMPOUNDED MEMBERSHIP FUND.
(State Trust Co.)

Balance as per last report	$600 00	
From General Fund, Dec. 29, 1898	500 00	
Life membership fees, H. Ward Leonard, W. F. B. Roquette and S. E. Doane	300 00	
Accrued Interest	13 44	$1,413 44

CASH BALANCES, MAY 1, 1899.

General Fund, Mercantile Bank	$2,664 46
Building Fund, Mercantile Trust Co.	990 48
Compounded Membership Fund, State Trust Co.	1,413 44
	$5,068 38

The Secretary and Treasurer have been authorized by Council to establish a Reserve Fund in an approved trust company in order that a larger proportion of current funds may also draw interest at 2 per cent.

GEORGE A. HAMILTON,

Treasurer.

The tellers subsequently presented the following report:

NEW YORK, May 18th, 1899.

TO THE AMERICAN INSTITUTE OF ELECTRICAL ENGINEERS.

The following is the result obtained from counting the ballots opened at meeting May 16th, 1899:

FOR PRESIDENT.

Total Number of Votes Cast........321.

Arthur E Kennelly	306	F. A. Pickernell	1
Charles P. Steinmetz	3	M. I. Pupin	1
L. B. Stillwell	3	B. J. Arnold	1
D. C. Jackson	2	H. J. Ryan	1
T. A. Edison	1	E. L. Nichols	1
T. D. Lockwood	1		

Total...............321

FOR VICE-PRESIDENTS.

Total Number of Votes Cast.... 953

J. W. Lieb, Jr	304	E. G. Bernard	1
Chas. F. Scott	304	F. B. Crocker	1
L. B. Stillwell	302	Gano S. Dunn	1
B. J. Arnold	7	S. Dana Greene	1
C. O. Mailloux	6	Carl Hering	1
F. A. Pickernell	6	J. W. Howell	1
E. W. Rice, Jr	4	D. C. Jackson	1
Ernest Merritt	3	A. E. Kennelly	1
R. D. Mershon	2	W. Maver, Jr	1
W. A. Anthony	1	R. H. Pierce	1
R. N Baylis	1	H. J. Ryan	1
Frederick Bedell	1	C. P. Steinmetz	1

Total..................953

FOR MANAGERS.

Total Number of Votes Cast........1278.

C. S. Bradley	314	W. J. Hammer	1
W. D. Weaver	311	Caryl D. Haskins	1
S. Dana Greene	309	A. S. Hibbard	1
C. O. Mailloux	294	A. E. Kennelly	1
W. S Barstow	7	John Langton	1
A. V. Abbott	7	L. B. Marks	1
E. J. Berg	4	Wm. Maver, Jr	1
Louis Bell	2	Ralph D. Mershon	1
Carl Hering	2	F. A. C. Perrine	1
Alex Dow	2	E. W. Rice, Jr	1
B. J. Arnold	1	R. E. Richardson	1
R. N. Baylis	1	W. L. Robb	1
Frederick Bedell	1	C. F. Scott	1
G. W. Blodgett	1	L. Stieringer	1
Douglas Burnett	1	C. A. Terry	1
J. B. Cahoon	1	Edward Weston	1
F. J. Dommerque	1	J. G. White	1
S. D. Field	1	A. J. Wurts	1

Total..................1278.

FOR TREASURER.

Total Number of Votes Cast........321

George A. Hamilton........ ...321 |

Total ....321.

FOR SECRETARY.

Total Number of Votes Cast ....321.

R. W. Pope............ ...... 320 | Geo. T. Hanchett.............. 1

Total....... ....321.

The total number of voting envelopes deposited was 348. Out of these, twelve did not bear the name of the voter on the outside envelope, and were therefore rejected. Other ballots were thrown out owing to the following informalities: Ballots were not enclosed in an inner envelope. Others had the name of the voter written upon them. After rejecting the above for non-compliance with the Constitution, there remained 321 ballots which were counted with the above result.

Respectfully submitted,

RALPH W. POPE,
A. A. KNUDSON,
Tellers.

The Proxy Committee reported the following list of proxies held by the members named:

R. W. Pope	111
Blank	11
George A. Hamilton	7
Cary T. Hutchinson	7
C. P. Steinmetz	7
C. O. Mailloux	2
T. C. Martin	2
Samuel Sheldon	2
W. D. Weaver	2
T. D. Lockwood	1
F. A. Pickernell	1
Total	153

The following paper on "The Multiple Unit System of Electric Railways" was then read by Mr. Frank J. Sprague:

A paper presented at the Sixteenth Annual Meeting of the American Institute of Electrical Engineers, New York, May 16th, 1899, President Kennelly in the Chair.

THE MULTIPLE UNIT SYSTEM OF ELECTRIC RAILWAYS.

BY FRANK J. SPRAGUE.

In May, 1887, a contract was signed for installing in the city of Richmond, Virginia, an electric railway which marked the active beginning of the modern development, for it proved to be the pioneer in most all the essentials of the present trolley system. It was not a long contract, but its terms were somewhat remarkable, being dictated by enthusiasm and self-confidence rather than by ordinary commercial rules.

It provided that a system (existing then only on a blue-print, except that the general motor ideas had been experimentally developed on the 34th street branch of the Manhattan Elevated Railroad) should be installed in ninety days, on an unbuilt road eleven miles in length, with twenty-nine curves, straight grades as high as 8 per cent., and grades on curves equivalent to 12 per cent., embracing a central station of 300 H. P., and equipments for forty cars, and for this $120,000 in cash was to be paid if the system "was satisfactory to the railway company."

The net loss to the Sprague Electric Railway and Motor Company on this contract was fully $100,000. The rest is history—the history of an unprecedented industrial development of such a character that every individual connected with the Richmond road through all its vicissitudes may well take a personal pride in it.

According to statistics published in the *Street Railway Journal* in February, 1899, there were in operation, by the close of 1898, in the United States alone, out of a total of 17,291 miles of electric, cable and horse car tracks, 15,672 miles with electrical equipment, comprising 36,429 motor cars and 7,914 trail cars.

The capitalized liabilities of these electric roads were close on to $1,500,000,000.

Ten years later, in May, 1897, another contract was signed, this time individually, for replacing the operative steam equipment on the South Side Elevated Railroad of Chicago by an electrical equipment on a new method, which, if successful, was destined to mark the abolition of steam and locomotive systems of any character on urban, interurban and suburban traffic, the next great field of electric railway development.

This contract was something like the other. The commercial conditions were onerous, and the professional and financial risks were great, such as might well make at least the officials and engineers of the road gravely hesitate, for the multiple unit system, absolutely untried in commercial practice, had to be reduced to practical operation on a scale of development and under conditions never before attempted in electric railroading even in Richmond.

It may well be asked: What was the warrant—what the necessity of such a contract? The answer is based primarily on the fact that rapid transit is the science of competitive railroading, and if by wheeled vehicles, ultimately reduces to a question of the proportion of weight upon the driving wheels.

All other matters entering into the question for any given case and set of conditions, such as schedule speed, traffic capacity, extent of equipment, total investment, frequency of service, operating cost, and even safety and reliability of service, are incidental to and directly or indirectly dependent upon the adhesion of the driving wheels of the vehicles to the track.

The fastest possible car movement between stations can always, under equal conditions of equipment, load, grade and power supply, be made by the vehicle which has the greatest percentage of weight on the drivers.

Therefore definite theoretical and practical limits exist for railroad schedule speeds under any given conditions, and the highest schedules in any case can only be made by a train system which preserves under all circumstances the specific characteristics of a motor vehicle with 100 per cent. weight on the drivers.

In the present stage of development of rapid transit systems for urban, suburban and interurban service, where stations are close together, traffic much congested morning and evening, and yard and terminal facilities limited and costly, high schedule speeds are absolutely essential. How shall they be had?

There are three distinct and generic methods of railroad passenger transportation as follows:

The single car, operating independently.

The locomotive, pulling trail cars.

The multiple unit system, or aggregation of transportation units, each fully equipped, into trains, and provided with a secondary control.

The first received its great impulse at Richmond in 1887-8. Its history and characteristics, as illustrated by the tens of thousands of cars in daily operation, need no detailed description.

Each car is a motor unit, with large effective driving weight, from 80 per cent. to 100 per cent., equipped with hand control, but incapable of aggregation into trains with localized control.

This system broadly includes all modern street railways.

The second is the locomotive system, following steam precedents, and dictated by the limitations of steam engineering, in which there is concentrated in a single unit the weight and power necessary to handle a train under given conditions. This locomotive idea has taken two forms, one of which copies one or another of the many types of steam locomotives, with such modifications as are permissible with electric motors, but which, despite the remarkable general progress of electric railways, still finds comparatively few applications in actual practice.

Notable among these are the Baltimore and Ohio tunnel locomotives in Baltimore, and the proposed equipment for the Central London Railway.

Among the earliest, if not the first, of the large locomotives is one of 1,000 H. P. capacity, built by the writer and his associates for the North American Co. about seven years ago.

Another form of the locomotive may be described as the locomotive car, which consists of a car body of the usual form, arranged to carry passengers, with one or both trucks equipped with motors, and hence with the weight distributed over a considerable distance, and with, as in the other case, hand control provided at either end of the car.

Such a one was experimented with by the writer on the 34th street branch of the Manhattan elevated in 1886-7, where was used the first modern railway motor, and a special car was built about the same time which was to have had an equipment of two 75 H. P. motors on each truck. This was before the days when the Richmond road was built, and therefore before the modern advance in electric railroading. This type of locomotive car was used on the Intramural Railroad in Chicago during the World's Fair, and is now in operation on the Metropolitan and Lake Street Elevated Railways in Chicago.

A modification of this locomotive car plan has been more recently proposed, which consists in putting a locomotive car at each end of the train, passing the main circuits through all the other cars, and providing duplicate hand controls at each end of each locomotive car for the eight motors constituting their equipment. The system is absolutely untried, presents innumerable difficulties, and has about all of the defects of the locomotive system, but constitutes an acknowledgement of the necessity of greater weight on drivers and greater power for meeting the requirements of modern transportation.

In matters of transportation, the passenger's demand and the wishes of an operating manager are not always alike. The passenger requires for his convenience the most frequent time intervals, the shortest station waits, and the highest possible schedule speed. The railway manager is apt to concentrate loads, increase the time intervals, and let the passenger wait, but in so doing he may lose the passenger. With a locomotive car system this is the inevitable result, because otherwise the entire motive equipment would be kept in continuous operation at low economy and at great expense.

All these methods—the single car, the locomotive, the locomotive car and the doubling up of locomotive cars—fall short of meeting the requirements of a flexible railway system to be operated on a high schedule.

The single high-powered car, using all of its weight on the drivers, needs no commentary so far as ordinary application is concerned, but the methods proposed for the aggregation of cars, and the handling of trains through the medium of a locomotive or locomotive car, or aggregation of hand-controlled locomotives occupying fixed positions, utterly ignore the possibilities of electric application, and the advantages manifest in every car operated on the street. In some form or other this has been recognized for a number of years, and it occurred to a number of engineers that, for increased adhesion and to provide more power with distributed weight, motors could be distributed throughout the train, the mains carried through it, and the system governed by a controller at the leading end.

One of the earliest of these proposals was made before the Society of Arts, in Boston, in 1885, just prior to conducting experiments on the elevated railroad, at which time I contemplated the use of motors on each car, or every other car, and a pilot locomotive or car containing an adjustable controlling apparatus which could be made effective for handling one or more cars. This project,

however, never reached fruition, and of course fell short of the possibilities.

Much more seemed certainly feasible. The excuse for the last mentioned proposal is found in the evident engineering truth that if greater power is applied to a train, and a high percentage of the weight on the drivers utilized during acceleration, higher schedules with reduced strains are possible.

Considering for a moment a single car as a unit, and putting all the available power in the motors connected to each of the axles which space permits, it is readily possible to put on a motor equipment which will develop over 20 H. P. per ton moved, and to use 100 per cent. of the weight on the drivers. The possibilities of this unit, that is using the entire weight of the car for traction, and all the power which can be put within the space permitted, is the limit, and absolutely the only limit of the possibility of the speed to be attained by an electric car. If now this unit is lengthened, that is, cars aggregated into a train, and the same ratio of weight on the drivers and the same H. P. per ton is maintained, then it matters not what the length of the unit, identically the same schedules can be made with the train as with the single car.

The most effective train operation, however, requires something more than schedule speed, and it seemed that considered from a competitive standpoint, and with the idea of gathering every passenger possible, the proper method of operating a railroad should be something as follows:

Starting at the time of least traffic, to operate the smallest allowable unit at intervals determined by the ratio of the increased cost of operation to the increase of passenger receipts to be obtained by shortening the interval. Then, as traffic increases, to shorten up this time interval as far as is consistent with safety, then to increase the size of train unit while maintaining the same interval and high schedule to take care of the greater traffic.

It is said that smaller train units cost more to operate than larger ones. This is to a certain extent true, but against this is the simple fact that on the scale of wages paid on many railroads the difference in total cost between operating two two-car trains and one four-car train is one passenger per car for every fifty stations as spaced on the elevated railroads in New York.

In view of this fact it can hardly be questioned that if shorter intervals are made possible, then more passengers would be gathered than represented by these differences, and trains would, if a practical system were devised, be operated in any length from one car up.

These, I think I may fairly say, were the views which finally came to be held by such transportation authorities as Chief Engineer Wallace, of the Illinois Central Railroad, and Chief Engineer Cornell, of the Brooklyn elevated, in the spring of 1897, and in this connection it is interesting to note a chronological review of various proposals which had from time to time been made for elevated railroad equipment and operation, which is appended to this paper, which will serve to illustrate a diversity of ideas and recommendations which have done much to bring ridicule upon the profession of electrical engineering.

This review is not intended to give a complete or detailed history of electric railway development, but is a running commentary on a variety of proposals made for train operation on elevated or suburban railroads from the year 1880 to the present time.

A survey of this record for the first seventeen years, up to and including the first proposals made as late as the spring of 1897 to the South Side road, shows that with the exception of offers made by me at various times, beginning at the Society of Arts, in Boston, in 1885, and ending in definite proposals to the Manhattan Elevated Railway in 1896 and 1897, and later, there were no propositions, or even a suggestion, from any manufacturing corporation or individual to equip a railroad on any other than a locomotive or locomotive car plan, with the single exception that on the Liverpool Overhead Railway, two-car trains are operated as a unit, each unit having a motor disposed at the leading and back ends, and with a hand controller at each end.

Typical important installations were, on the locomotive plan pure and simple, in 1895 at Baltimore, and on the locomotive car plan, under the supervision of Mr. W. E. Baker, on the Intramural road at the World's Fair in Chicago, in 1893, and on the Metropolitan West Side Elevated Railroad under the same supervision in 1895, at the former of which Mr. Baker had to override recommendations in favor of a locomotive.

The variety of ideas indicated by these notes, and the inexcusably wide divergence of expression concerning the commonest engineering facts, as well the crudeness of many electric railway proposals, were never more sharply shown than in a paper by Mr. Wallace, of the Illinois Central Railroad, on the subject of "The Substitution of Electricity for Steam as a Motive Power for Suburban Traffic," before the American Society of Civil Engineers, February 3, 1897, and in the discussion which followed it.

Mr. Wallace, having, in December, 1891, been directed by the

management of the Illinois Central Railroad, of which he was then the Chief Engineer, to investigate the subject of adopting electricity on the Illinois Central Suburban Railroad, after a careful consideration of the requirements of the road, issued a list of forty-five categorical questions covering the operation of a fairly fixed equipment at twenty miles an hour. These questions were sent to all the various electrical companies except the Sprague, which had at that time been absorbed by the Edison General Electric Company. Consequently, for the old Sprague company and for myself I must disclaim any responsibility for the variety of results.

I will not attempt to review the answers to all the inquiries as presented by Mr. Wallace, only touching upon a few of them to illustrate the disparity of recommendations made, but for an interesting detail comparison refer to the comments at the meeting by Mr. Charles Henry Davis, from Mr. Wallace, partly quoting, that: "The engineers giving this matter their attention have been enthusiastic electricians; they have seldom been practical or expert mechanics, and the writer would add, usually inexperienced as railroad engineers."

But let us briefly take note of the recommendations.

The motor capacity varied from 100 H. P. divided into four units to 200 H. P. divided into two units, and distributed from one to two motors on each of two trucks under a locomotive car carrying passengers, or on the other hand aggregated into a locomotive pure and simple without passenger carrying capacity.

Both ring and drum armature constructions were recommended, and driving wheels of from 30″ to 42″ diameter.

About every possible form of axle driving, except chain or belt transmission, was proposed. One company was indifferent as to whether the motors were directly on the axles, or gear transmission was adopted; another recommended spur gearing; another, cranks and parallel rods; and still another no form of gearing under any circumstances, but an armature mounted on a hollow shaft surrounding the axle.

The central station equipment varied from 4,800 to 18,000 H. P., and the steam units from 400 H. P., driving single machines, to 1,500 H. P. driving double machines.

Horizontal compound and vertical triples had their advocates, and rope or belt as well as direct connections between engines and dynamos.

The space required for the central station varied from 12,000 to 75,000 square feet, and the cost of power plant, not including real estate or buildings, from $320,000 to $1,169,000.

Amount of fuel required per H. P. from two to three one-half pounds.

The annual cost of power plant operation ran from $60,000 to $225,000.

The potential varied from 500 to 1,000 volts.

The cost of trolley lines and feed wires from $40,000 to $172,000, and repairs to the same and other line expenses from nothing to $23.50 a day.

The practical curvatures from "50-foot circle" to "150 feet radius."

On one subject there was unanimity of agreement, the transmission was to be by continuous current, and by overhead trolley. Despite Mr. Wallace's request for information about a third rail supply, it was incontinently waived aside.

The multiple unit system was not in any form proposed, but there was discussion on the subject of the relative advantages of small independent units versus trains.

The recommendations made, hardly need extended comment, and one can well imagine the reasons which then stopped any further action on the part of the Illinois Central Railroad.

The whole paper is one of great interest, but from the discussion I will extract only a few comments which, in view of the immediate subsequent developments, are important.

Mr. Thomas C. Clarke, a Past-President of the society, stated as follows:

"The author, under the head of 'minor problems,' speaks of the size of transportation units and whether independent motors of large power shall be used to haul long trains of trailers, or whether small transportation units, run at more frequent intervals, shall be adopted, with motors on the cars. In designing the rolling stock and structure of elevated electric railways in cities, this is the main point, and not one of minor consideration. Neglect to study this and to come to the correct conclusion had led to the financial failure of one of the largest electric elevated railways that has been constructed, and will lead to the financial failure of all others that follow the same lines.

"Carrying passengers in a city does not differ from any other business. The first requisite is to get abundant traffic; the second, to handle it with economy.

"Elevated lines run in competition with surface lines, and charge the same fare. The surface lines can beat them in all points but one. They afford more frequent stops; there is no climbing of

stairs; cost of construction, and, consequently, interest is less, and the system of transfers to branch lines is a great accommodation to the public. The elevated trains, not being impeded by surface traffic, can make better time; but for that, no person would ride in them, except to escape crowding.

"Common sense would indicate that the managers of elevated lines should try to approach, so far as possible, the conditions which have made surface lines a success.

"Frequent stops can only be attained, without losing too much time, by having a great power of acceleration. Any amount of power can be sent from the central reservoir, but if the wheels of the car slip, a limit is reached. Therefore, instead of having only one-third of the weight of the train available for adhesion, as is the case where an electric locomotive draws a train of trailers, utilize the whole weight of the train and passengers by putting motors on every car, connected electrically and mechanically, and worked by a motorman at one end of the train. Another advantage resulting from this is that the gradients can be steepened, and the height of the station and their stairways reduced.

"If, in addition to this, short trains of light cars are used, the weight and cost of the structure can be greatly reduced, and the interest charges also. Small trains mean frequent trains to enable the traffic to be carried, and everybody knows there is no means of attracting traffic so powerful as that of frequent trains, as there is then no waiting at stations, which everybody hates.

"The summing up of the whole matter is, that to make the city elevated railway a success, the surface electric system must be copied, and placed above obstructions from other traffic, and not the steam locomotive system of long trains at greater intervals.

"The process of evolution which develops everything along the fittest lines will make the city elevated railway of the future, one of light structure, carrying light and very frequent trains, with motors on the cars themselves—a development of street trolley lines, and not of steam locomotive railroads."

Mr. Walter H. Knight stated that: "The whole object of the elevated railroad is speed, and speed cannot be made with short headways. It would make little difference, so far as speed is concerned, whether the cars were all equipped with motors, or all the electric apparatus concentrated on one car."

Mr. Wallace stated that: "One of the practical difficulties in the way of placing motors on each axle of the car and on several cars of the train, and coupling them up so that they can all be used

and under the control of one motorman, is that, so far as the author's investigations have gone, there is as yet no perfect and adequate controller in use in the United States which will provide for the proper manipulation of more than two motors," and his conclusions seemed to be that while a train system did not give that which was necessary, nothing had been presented to him in answer to all his inquiries and his painstaking research which gave him any promise of successful departure from his then existing method of operation.

There is small cause to wonder that the project for electrically equipping the Illinois Suburban was for the time abandoned.

At the time when Mr. Wallace's paper was presented, a committee, including himself and some other officers of the road, had been formed, with Mr. John Lundie as engineering secretary, and with a number of assistants was making some further investigations as to the possibilities of electric application. A report was made about the end of the year, and accompanying it was a proposal from me to guarantee a twenty-four and one-half mile schedule on the suburban service of the road instead of the eighteen and one-half which was then being accomplished by steam, and, if I am not mistaken, all further consideration of a locomotive pulling trailers was abandoned.

I think, as events have turned out, that with regard to the diametrically opposed views presented by Mr. Clarke and Mr. Knight, the former may well rest content with the position he assumed.

Such was the generally unsatisfactory state of electric railway development for all else than ordinary street roads in the spring of 1897, and the conclusions which I have already given, together with apparent advantages which would accrue, pointed unerringly to the necessity of the third generic system of railway equipment and operation, that which I have termed the "*multiple unit system*," which is the most logical, and seems to me a finality in, railroad development. It may be briefly described as a semi-automatic system of control which permits of the aggregation of two or more transportation units, each equipped with sufficient power only to fulfil the requirements of that unit, with means at two or more points on the unit for operating it through a secondary control, and a "train line" for allowing two or more of such units, grouped together without regard to end relation or sequence, to be simultaneously operated from any point in the aggregation.

For any given weight to be moved, whether it be in one or two cars, there is a certain capacity of motive equipment with which

it is best to operate it under fixed conditions, and that is the motor equipment which should be put on that unit, not something either larger or smaller, and then when more capacity is required, to simply add another unit of like character.

A unit may be a single car or a pair of cars, and the number of motors used whatever desired. The logical equipment is two motors for each car, and when so equipped the importance of some of the practical results are emphasized.

Among the advantages which such a general system when fully developed must possess, may be mentioned first:

Similarity of Equipment.—This gives absolute flexibility of train operation.

It ensures like characteristics for trains, whatever the length, and whatever the combination of cars.

The motor equipment is directly proportional to the number of car units.

There is a practically fixed relation between the weight on the drivers and the total load, whatever the length of train, and it is a matter of indifference to the motorman whether he is operating one car or any aggregation of car units in a train, for its characteristics are the same.

Independence and Facility of Operation.—Each car being lighted, heated and braked independently, has independent movement in yards or car houses or on the tracks, wherever stored, and thus inspection, repairs and train combinations are facilitated.

The head and tail switching operations of locomotive practice are entirely abolished.

Trains in whole or in part can be reversed at any cross-over, thus reducing the dead mileage and intensifying the car movement to meet the conditions of passenger movement.

Cars can be added to or taken from a train in a third of the time that is possible with a locomotive system.

Where a system has main tracks with branches, car units for the different branches can be aggregated on the main line and then split at the junction, thus preserving the time intervals on the branches but doubling the distance intervals on the crowded sections.

The fullest use can be made of all sidings and tracks, wherever located, for storage, and in a large measure for inspection, which ensures less dead mileage and useless returns, and effects concentration of car movement which is impossible where the cars must be stored in one place.

Increased Schedules.—Any required rate of acceleration or schedule speed up to the maximum becomes possible, thus giving the highest schedule with any given maximum, and the lowest maximum with any given schedule.

A partial equipment may be made by equipping alternate cars, and this schedule later increased by additions to the existing equipment without changing its character.

Local and express service can be operated with greater or less aggregation of motor equipments.

It has been suggested that with a locomotive system, when trains are reduced in length and the service on the road is diminished, the locomotive car can then increase the schedule, and that during the times of heavier traffic it still has capacity enough to pull a train. Such an argument is a reflection on the common sense of a railway manager, and such practice a parody on railway operation. The time above all when schedule speed, capacity and effective operation are required is when traffic is greatest and the road most liable to congestion. It is difficult to see how any engineer can seriously offer such an argument in support of locomotive practice, for it is directly contrary to the most vital requirements on a railroad.

If, as is vital in competitive service, a high schedule is necessary, and ignoring for the moment all questions about relative strains, weights, facility of making up and controlling trains, and the advantages of variable train lengths and intervals, when we come to six or seven-car train units a high schedule with short interval stations is impossible except with two heavy four-motor locomotive cars or with every car equipped with a pair of motors. And from every point of view, the latter is preferable.

Reduced Strains.—This is of importance where elevated structures or bridges are used, especially when already possibly strained.

It is apparent that the weight of cars, truck and motive equipment between columns is necessarily less than with any locomotive or locomotive car system.

All the longitudinal or shearing strains are greatly reduced.

The hammering on the rail joints, with the resulting shock to the structure and to the moving train, will be diminished because of the less weight per driver.

The thrust strains for any given rate of acceleration are equalized and distributed over a considerable length of structure, and become practically the reverse of the braking strains.

The strains on car bodies, platforms and couplers are reduced to a minimum.

Increased Density.—The safe time interval between trains for a given schedule and for any given length of train and station stop is dependent upon the maximum speed and the rates of acceleration and braking, and the greater these latter with any given schedule, that is, the lower the maximum speed and consequently the less the travel of the train after the brakes are applied, which distance varies roughly as the square of the speed at the time of applying the brakes, the shorter can be both the time and the distance interval between trains.

If there were an infinite rate of acceleration and braking, then there would practically be necessary, barring accidents, only that time limit between trains as is occupied by a train at and blanketing a station. In practice a motorman will approach a station with more confidence and under closer headway when his maximum speeds are low, and the braking distance which he travels short, and when he has confidence that the train ahead, once started, will promptly accelerate and increase speed while that of his train is rapidly diminishing.

It is apparent, of course, that the length of a train is only limited by the platform accommodation.

Better Equipment.—From this standpoint better motor manufacture is ensured. There are fixed limitations of wheel base, track gauge, wheel seat, diameter of axles and distances between axle and bolster, and hence there are practical limitations to the outside dimensions of motors. The smaller the capacity of the machine put into that space, the greater the margin for increase of dimensions of the essential working parts, such as bearings, gears and commutators, and the greater the freedom for inspection. Likewise, also, is there greater space for the application of any kind of brakes, electric or mechanical.

Reduced Number of Cars.—With any given maximum hourly mileage, the number of cars in service or on relay will vary inversely as the schedule. This advantage is further augmented by those already instanced, the concentration of car movements where most desired, and the storage of cars at the most convenient points, with consequent less dead mileage.

Simplicity of Operation.—The operation of the multiple unit system becomes the simplest. Every motor car or pair being a transportation unit, and every aggregation of such being, so far as the motorman is concerned, simply an extension in the length of the unit without in any manner changing its character, the operation becomes almost automatic, a sort of second habit. Like

hand and like train movement exist, whatever the combination and wherever the motorman is situated.

The making up of trains, so far as electrical features are concerned, is as simple as coupling up an air hose.

No main currents are carried from car to car, only small currents, through reversible jumpers, and the electrical combinations are effected automatically, however the trains are made up and whatever the end relation of the cars.

Protected by the automatic features, a child of ten years can handle full-sized trains on regular service with less trouble, so far as the electrical apparatus is concerned, and with less instruction than is required for the simplest form of air brake.

Ease of Inspection.—The train line and the main motor circuits being absolutely independent, and provision being made on any car for cutting out a set of motors, facility exists for an easy inspection, wherever the cars are located. Almost all the working parts of the motors can be inspected through the trap door in the bottom of the car, and since the cars have independent movement and can be rapidly run through an inspection shed over a pit, a little practice enables an inspector to make the most rapid survey of trucks, brake rigging, motors and everything else which is under a car.

Economy.—Transportation wages per car mile, the largest element of cost, are reduced because of the simplicity of operation, and because of the increased schedules. With the same efficiency there is less power per car mile expended, and hence less coal burned, for any given high schedule with like conditions of traffic than with a lower rate of acceleration because of the less amount thrown away in braking. The increase of power required because of low acceleration over high is anywhere from 25 per cent. to 50 per cent.

When it is realized that a system like the elevated railroad would use only one-sixth of the power actually now used if it made no stops, the importance of this fact may be seen.

The question of coal economy is of less importance, however, than many other features of railroading, and, from a financial standpoint far less important than getting absolute freedom in determining train intervals and train lengths. In this connection it should be noted that altogether too little consideration is given to the question of car construction and car weights, and it seems to be forgotten by many engineers that useless tons of dead weight moved represents unnecessary investment in plant and a continu-

ous charge against operating expenses, and it is about as sensible to ignore this question as it would be to add pig lead to a car having all of its weight on its drivers to increase its traction. If half the energy was spent in reducing useless tonnage moved, that there is in bargaining on the cost per kilo-watt of apparatus, the cost per car mile and the ratio of operating expenses to receipts would be gratifyingly reduced.

Safety.—The highest safety is essential. In the case of failure of brakes, or on slippery rails, the machines throughout the entire train can be safely reversed. The current input to the machines is automatically limited on each one to its safe capacity. In case an accident should happen to an operator and he lets go of his controlling handle, the entire power is instantly removed from the train, and in case the controlling apparatus on the leading car should become disabled, the train can be operated from either end of any other car.

In fogs and on slippery rails a fixed schedule can be maintained more effectively because of the lower maximum speed, the less distance traveled in braking, the greater confidence in approaching a station, and the promptness of the leading train in getting away.

On account of the reserve capacity of the machines it is possible to make up time, and also clear a road, which is a matter of the gravest importance on a congested system.

The automatic cutting off of current will have an important bearing in a not distant future when a legislature is apt to, and should, prohibit the operation of a train with only one man in front unless there is some certain method of removing the driving power in case of accident to the operator. This is an instance of where an apparently small thing, possibly determining the employment of several hundred extra men, has a vital importance.

Least Cost.—The multiple unit system means lowest first cost as well as lowest cost of operation. This is contrary to first impression, but the explanation is simple in that the cost of the delivery of electrical energy to the car shoes per unit of constant use is eight to ten times the cost per unit of maximum capacity of car equipments, and by using the higher rate of acceleration rather than the lower for any given high schedule, the aggregate cost of the total equipment from power-house to car equipments for any given hourly mileage is less, because, notwithstanding the increased cost of car equipment, the difference of economy creates a saving in that portion of the electrical equipment, that is generation and distribution, which costs so many times more per unit equipment

than the units of car equipment, that the latter increase is more than made up by the saving in the former.

All this is readily proven, for I know of no problem presenting greater and more interesting possibilities of exact determination, so far as results are concerned, than that of electrical railway engineering; yet, on the other hand, I know of none in which there is a more reckless disregard of possibilities than in this very profession. In this, as well as in every other problem of kinetics or construction, and just as certainly as in the construction of a bridge, great increase of first cost, and cost of operation, may accrue from a disregard of the essential relations of all parts of the system, and on the other hand great savings may be achieved by a thorough knowledge of them.

Despite these facts, it is curious to note oftentimes the inversion of the sound engineering with which the consideration of the electrical equipments of a road is often attended.

On any existing road whose traffic is known, the problem, put in the briefest form, *should* be:

Given the existing maximum car mileage and schedule, how best and most cheaply, both as to first cost and cost of operation, most quickly and with the least interference with service, and without increase of strains on elevated structures or bridges, can the existing mileage be maintained, how much can it be safely increased, what possible schedules can be made, and what will be the effect on the traffic and operating expenses of the road.

The fact that there is a most intimate connection between the generating, transmission and the motor parts of the equipment seems often to be lost sight of entirely, and yet even the ratio of gearing adopted on the car motor will affect the size of the power plant. The natural procedure would be to determine what results are desired, and then find the best method of getting them. Instead of that, oftentimes a purely empirical decision is made as to portions of the equipment, such as the capacity of the central station and size of its units, and the results, so far as the movement of cars is concerned, left to take care of themselves. This procedure reminds me of the architect who, wishing to erect a skyscraper, would decide upon the foundation without regard to the weight of his building or the character of the soil beneath it, or the engineer who would build a bridge without knowing the load which will be put upon it.

There is, in fact, the most intimate possible relation, as should be perfectly evident, between the various parts of the equipment,

and this relation is such that the costs of each part is seriously varied, with exactly the same schedule, grade and load conditions, by variations in the manner of making these schedules.

This is in no manner more effectively shown than in Mr. John Lundie's most interesting methods of detailing the essentials of first cost and cost of operation for various schedules under various rates of acceleration, all referred to a common factor, the percentage of weight on the drivers.

Such, then, are the practical advantages to be derived from a properly devised multiple unit equipment, but to be effective the details of the system had to be developed at great expense and much experience, to a state of absolute reliability and reasonable simplicity.

It may be stated, now, that the essentials of the multiple unit system are not complicated, despite the remarkable variety of functions which they have. They may be stated briefly to be as follows:

1. The master controllers on the platforms at each end of a transportation unit. They are of the simplest and most reliable character.

2. The master controller and train line cables, which become parts of the permanent wiring of a car, and are just as reliable and as simple as that for the lighting system. These secondary controlling cables are absolutely independent of the main motor circuits, and carry very small currents.

3. The jumpers, which are removable sections of the train line, and connect the parts of the latter which are permanent to each car, just as air hose couplings connect up a brake line.

4. The main controller, which is composed of the following parts:

Certain relays and a throttle, developed in electric elevator service.

Pilot motor with automatic limits, something like that used in elevator controls, but of more robust make.

A rheostat cylinder, with or without motor grouping switches, the parts similar to those of hand control.

A reverser with like parts, but independently operated.

The braking system, whether using automatic air or electric, is something like the multiple unit electric system. There is a train line with means at each end of each transportation unit for simultaneously applying the brakes. When automatic air is used, there is a train and equalizing line, a compressor with an automatic governor, illuminated gauges and a simple form of engineer's valve at the ends of each car for each transportation unit.

The Multiple Unit System on the South Side Elevated Railway of Chicago.

Like many other innovations, the opportunity to put the system which has just been described, and which promised so much, into operation was a long time coming. Many attempts had been made, with offers as already indicated to conduct experiments on a wholesale scale at my own expense, but with no satisfactory response, until in April, 1897, I was suddenly called in consultation on the South Side Elevated Railway in Chicago.

This road had passed into the hands of a receiver, had been reorganized, and in the spring of 1897, had, under its new and energetic president, Mr. Leslie Carter, and a progressive Board of Directors, decided to adopt electricity, with Messrs. Sargent and Lundy as engineers.

The original plan submitted by the various manufacturing companies proposed the usual locomotive car with either two or four-motor equipments, but many difficulties presented themselves in providing for the necessary power and weight to get the increased schedule speed demanded, as well as to meet other requirements. I at once saw the opportunity for a radical departure, and the opportunity to commercially put in operation a multiple unit system. The advantages of higher schedules, reduced weights, variable train lengths, more frequent trains, distributed motive equipment and increased economy being presented, with the plain statement that while the system was absolutely untried in railroad practice I was quite ready to back my recommendation by performance, found willing ears and the endorsement of the engineers, with the result that definite proposals resulted in a contract which in many ways was of similar character to that made for Richmond.

During the brief period of my transmission from the status of consulting engineer to that of contractor, a meeting in Chicago proved particularly interesting, for in the early part of April, 1897, scarcely more than two months after Mr. Wallace's paper before the Society of Civil Engineers, I had the pleasure of being present at a table when he made a statement about as follows:

"What I wish to do on way suburban traffic is to abolish the time table except at the dispatching terminus, and to send out frequent trains in succession whose length shall be one or a dozen cars according to the traffic requirements at the time of day, with orders to make the best time practicable on their round trip. In fact, I hope to see the time when I can run a train with a push button."

Turning to him, I said: "That is precisely what I am in Chicago for at present." In fact, my report in favor of the multiple unit system had already been made to the South Side road, and a proposal for its equipment tendered.

It is suggestive also that it was very shortly after this that Mr. Cornell independently expressed himself very much as had Mr. T. C. Clarke.

However, despite the apparent soundness of the engineering and railway principles involved in the multiple unit system, the record of thousands of individually equipped cars all over the world, the many shortcomings of railway equipments depending upon locomotive practice, and the success and extent of the secondary control of single motors in elevator work, when the proposed plans for the equipment of the South Side road were announced, the project met with the most radical and oftentimes unthinking objections from many electrical engineers. With the exception of the consulting engineers of the South Side road and a few former associates, whose confidence in my ability to carry out the contract was largely a personal one because of past relationship and acquaintance, and Mr. W. J. Clark, the then manager of the railway department of the General Electric Company, for whose personal support I am much indebted, I recall few instances of professional support.

I had, however, been through too many experiences of the kind to be discouraged as to the outcome, and I received cordial support from the various sub-contractors, who willingly accepted orders for material under conditions somewhat out of the usual, and it is to their active co-operation in this respect that much in the way of the possibilities of the multiple unit development on the South Side road is due.

The criticism which was poured in on the South Side officials, however, was not without result, for, realizing the gravity of the proposed departure in practice, the contract requirements were made of the most rigid character, and the conditions under which the equipment was to be installed were most exacting.

In fact, considering the importance of the contract, all the negotiations for its conclusion were somewhat out of the usual. With the exception of a short period of consultation in Chicago, most of the engineering correspondence was carried on by telegraph, and the contract in its final form was signed by my assistant, Mr. McKay, without my seeing it, while I was out of the country, the contract itself having been prepared by the officials, advisers and

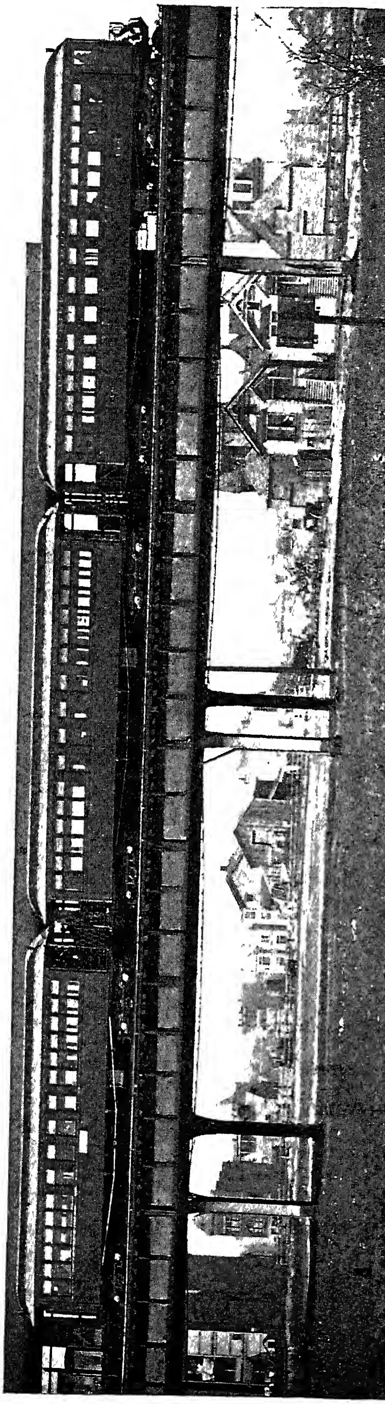


FIG. 1.—Three-Car Multiple Unit Train.

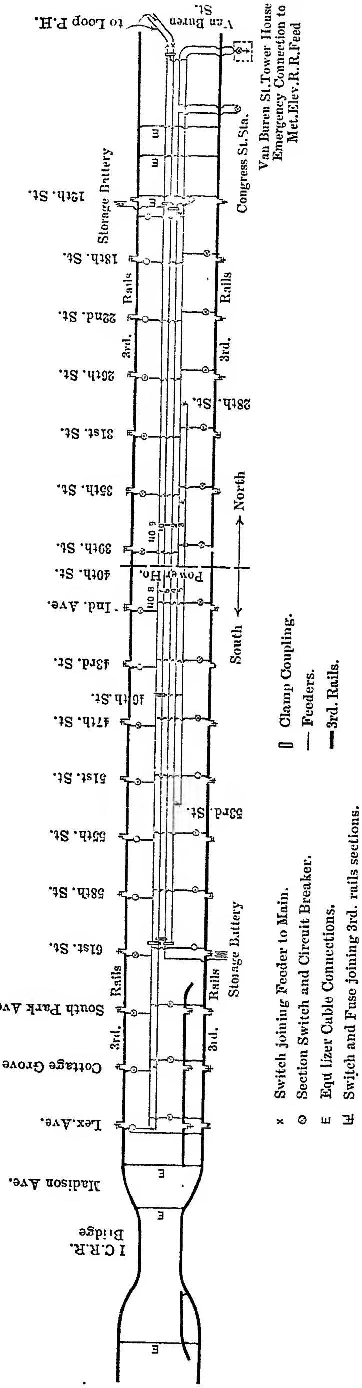


FIG. 2.—Diagram of Distribution System—South Side Elevated Railway.

engineers of the South Side road, with what care in protecting their own interest one can well imagine.

The physical conditions were as follows:

The existing road is a double track structure of the usual elevated type, extending from Congress street to Stony Island avenue, a distance of about eight miles. Plans were already made to connect it with the new "loop" in the heart of Chicago, on which the trains of the Metropolitan and Lake street roads were already operating, and which was to receive also the trains of the projected Northwestern elevated, with the prospect of grave congestion and the absolute necessity of freedom from serious blockades which would stall the entire elevated system of the city.

The road is paralleled by cable and electric street systems, by the Chicago and Rock Island road, and by the superb suburban service of the Illinois Central.

The existing equipment consisted of forty-six 28-ton Baldwin compound locomotives, and 180 standard 43-foot 15-ton cars equipped with Pintsch gas, steam heat and automatic air brakes.

The schedule speed on the main lines was fourteen to fourteen and one-half miles an hour; trains were operated at intervals of one and one-half minutes to half an hour, and in lengths of from two or five cars; the service, including the loop, would, in the cold weather, require 145 to 150 cars, and ten or fifteen cars would ordinarily be under normal repairs.

It was necessary to take this equipment in its then condition, remove ten or fifteen cars at a time from the structure, partially equip them, return them to the road to allow them to be retained in steam service, to again withdraw them, complete the equipment, and put them into electrical operation when the power-house was ready, jointly with steam trains, without crippling the service.

The contract required the supplying and installation on 120 cars of lights, heaters, motors and trucks, as well as the developing *de novo of* an entire new system of control, involving not only the actual construction of the controlling mechanisms, but the train system connected with it, such as couplers, jumpers, automatics, etc., the installation of a braking system, and the providing of both ends of the cars with vestibules or cabs. Nine-tenths of the apparatus was not of my own manufacture—even the motors were not of a commercial size.

The following were among the required conditions of operation:

The simultaneous control of two or more independently equipped motor cars, to start, accelerate, operate at any speed up to the

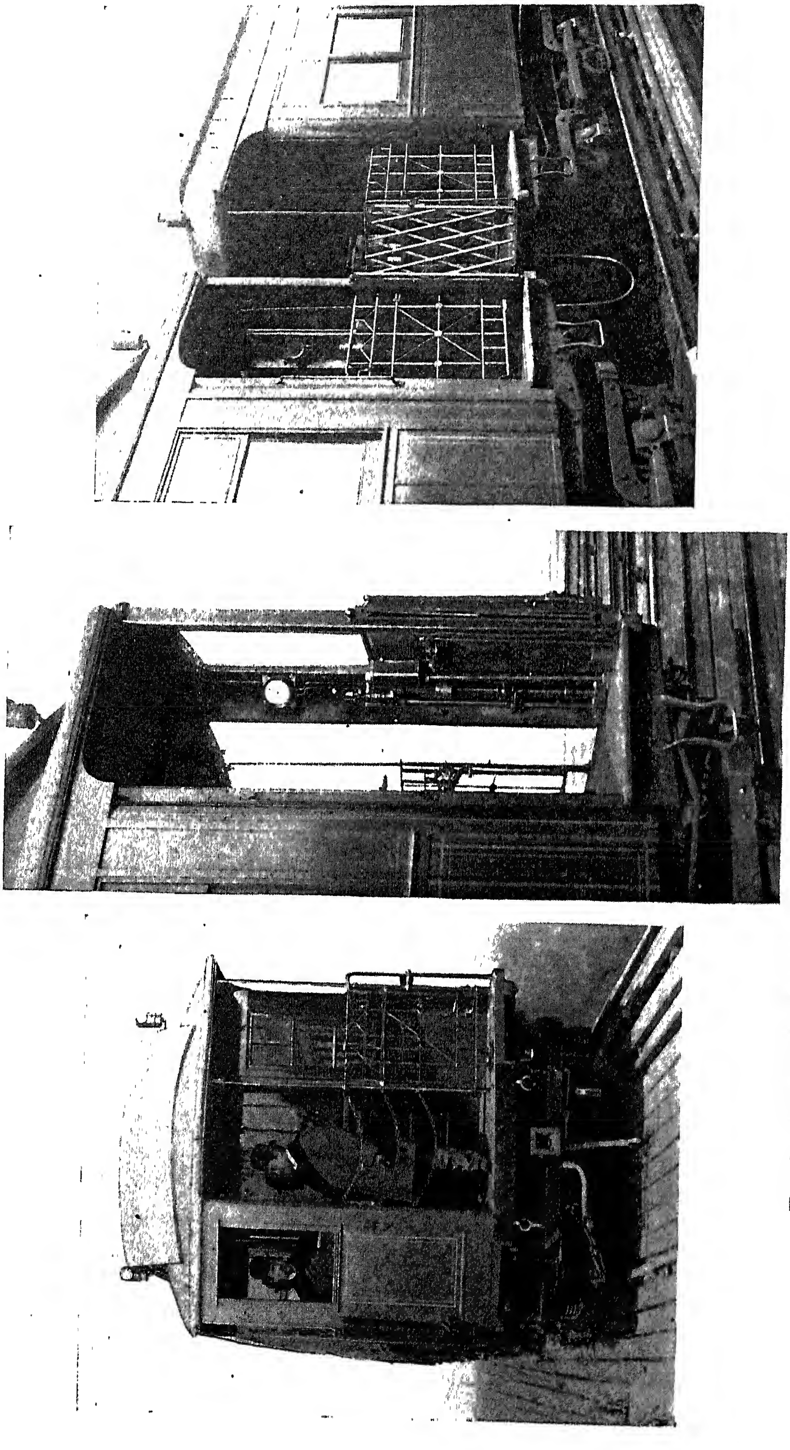


FIG. 3.—Details of Platform, Cab and Master Controlling Mechanism—Multiple Unit Train—1898.

maximum, slow down, and apply automatic brakes, all with practically uniform effect in each and every motor car.

The automatic reversal and braking of the machines and cars in case of failure of current, parting of train, or running onto a dead section.

With a normal potential of 500 volts, a single motor car, or any number connected together in a train, to be able to maintain a schedule speed between existing termini of fifteen miles per hour, with average stops not exceeding ten seconds for existing station distribution, and to be able to ascend a 2 per cent. grade at more than schedule speed.

The system of control to be such that any number of cars so equipped could be coupled together indiscriminately without regard to their sequence, and when so coupled, by identically the same movement to be controlled from any selected point at either end of any car, and the rate of acceleration, traction co-efficients, speed and braking conditions which characterize a single car to be duplicated in a train unit, no matter what the number of cars.

The automatic braking devices and electrically operated power brakes to furnish a perfect substitute for the air brake in use, in efficiency, reliability, and automatic action.

The contractor was to begin work on the equipment of 120 cars immediately upon signing of the contract, and to have six cars completely equipped, ready for operation and test concluded on or before July 15, 1897, on a standard track not less than one mile in length, to be supplied by him at his own expense; the test and the manner of its making, as well as its extent, to be prescribed by the officers and engineers of the road, and to be to their entire satisfaction. Should such test be unsatisfactory to any of these officials, or not to be conducted by the date set, then the right remained with the railway company to cancel the contract. Should the test prove satisfactory, the cars were to be delivered wherever required for further tests, the remaining 114 equipments to be progressed to completion by specified dates, and as soon as the South Side power-house and road were ready for electric operation, another test was to be made of twenty or more equipments under the actual service conditions of the road, which test was to extend over a period of at least ten days, and be made in such manner as required by, and to the satisfaction of the president and engineers of the company. In the event of these equipments proving unsatisfactory to any one of them, the company still had the right to cancel the contract, and to require a waiver of all claims against

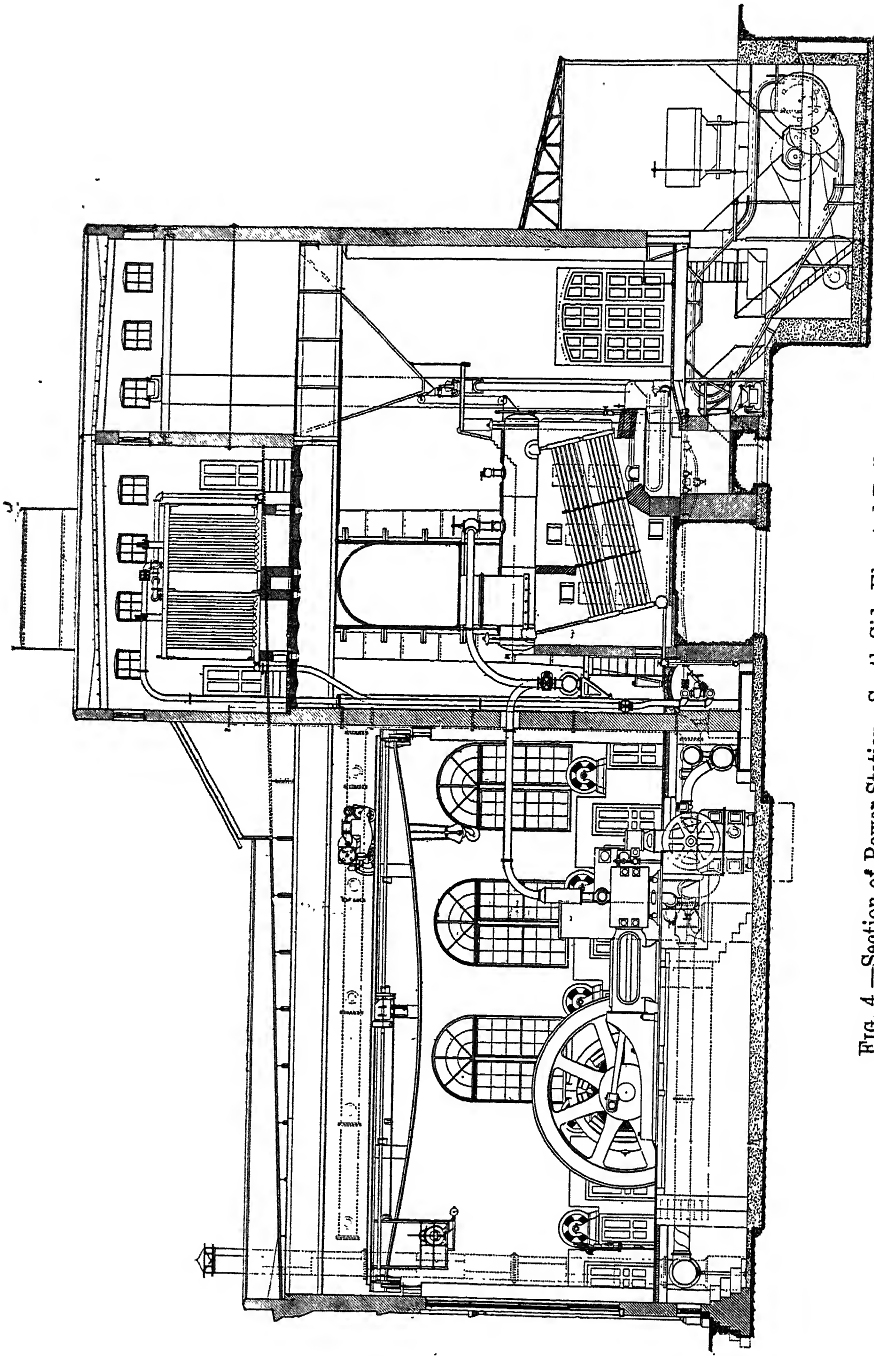
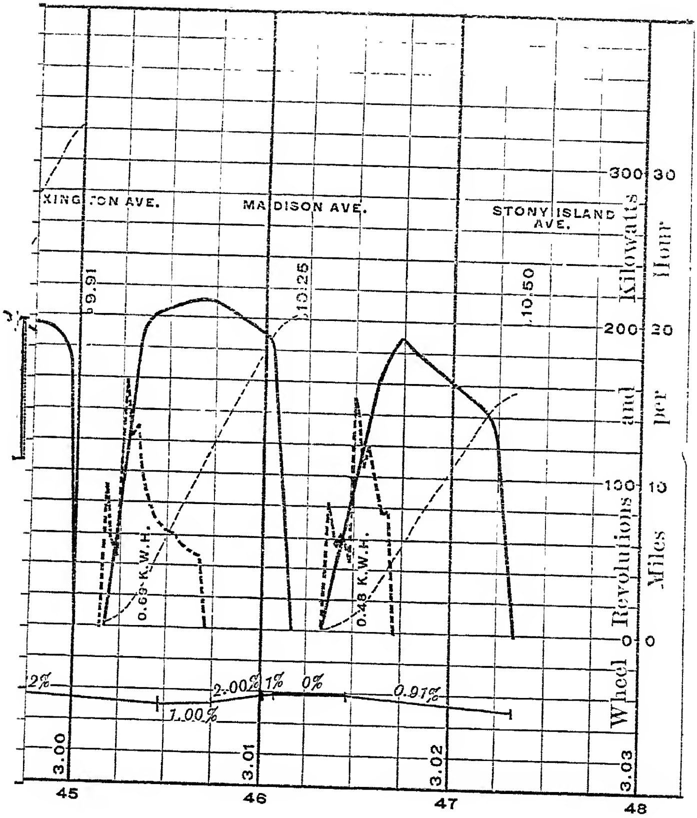


FIG. 4.—Section of Power Station—South Side Elevated Railway Company.



CAR EQUIPPED WITH 2 G. E. 57 MOTORS

it. No acceptance of any part of the equipment could be required by the contractor until after these specified tests. In addition, a $100,000 penal bond, in form drawn by the railroad company, for the carrying out of the contract, had to be filed.

All these conditions were accepted, and while the installation on the road, from the contractors' standpoint, bears a striking similarity to the immediate commercial outcome of the Richmond equipment, the results will probably be equally historical.

The progress of the experimental equipment was erratic, and many of the conditions unknown, for before the signing of the final contract I had gone abroad for the purpose of getting the elevator equipment for the Central London railway, an engineering proposition of no mean magnitude, but which was finally awarded under much the same conditions and risks. I did not return until after the middle of June, so that most of my instructions concerning the trial equipment were given by cable and the actual work of construction and preparation was done within thirty days.

However, on the 16th of July, 1897, two cars were put into operation on a private track, at Schenectady, in the yards of the General Electric Company, which company, as well as a number of other sub-contractors, had accepted conditional orders from me for the various portions of the equipment which they could supply, and had, as a condition of procuring the order, offered the use of their tracks for experimental purposes.

On the 26th of July, the fiftieth anniversary of the late Professor Moses G. Farmer's test of an electric car at Dover, N. H., a train of six cars, operated by my ten-year-old son, Frank D'Esmonde Sprague, was put into operation, and tests of the equipment in the presence of the officers and engineers of the South Side road were continued for several days. All the apparatus was of course temporary.

On November 17th, a train of five cars was put into operation on the loop and over the track of the Metropolitan Elevated Railroad, and continued for a number of weeks, operating sufficiently satisfactorily to warrant the completion of the contract which was then in active prosecution.

The first car was run on the South Side road April 15th; on April 20th, twenty cars were put into initial operation, seventeen of which came off by night because of defective rheostats, but by July 27th, locomotives had been entirely abandoned.

Subsequently thirty "train line" cars, for insertion into trains during periods of heaviest operation or on special occasions, were added, and since then thirty more cars have been fully equipped.

This review would not be complete without here acknowledging my many obligations to the officers and engineers of the South Side road for their confidence and patience, as well as the hearty co-operation and support of my own business and technical associates in the Sprague company, during many trying and critical periods.

A description of the actual equipment of the road is here given under the heads of power-house, track system, storage battery, and car equipment and control, with some notes as to the practical operation and the results obtained.

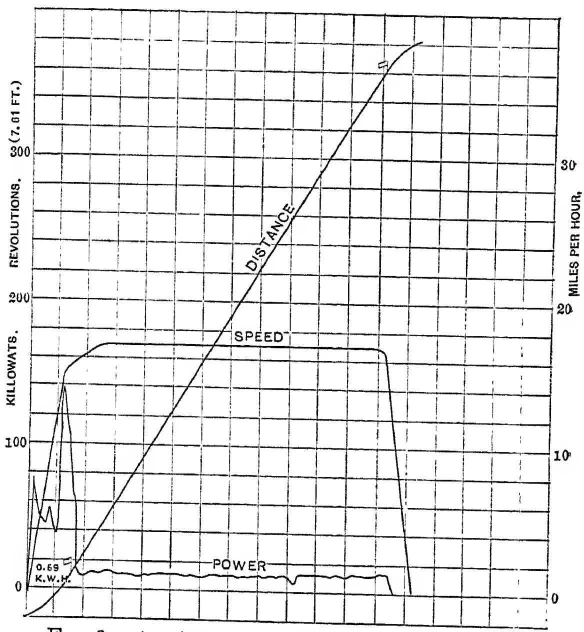


FIG. 6.—Acceleration and Series Operation Curve.

Power-House.—The power-house was built after plans by Messrs. Sargent and Lundy, and embodies several features which successfully obviate the disadvantage of a site removed from water supply sufficient for condensation, but which was chosen because it was near the center of distribution for the railroad system.

The building is of brick and iron, unpretentious in design, and the engine and boiler rooms are separated by a brick wall dividing the building longitudinally.

The boiler plant at first installed consists of four batteries of Babcock and Wilcox water tube boilers, rated at 400 H. P. each,

equipped with chain grate stokers filled from overhead coal bunkers of 1,000 tons capacity.

The chain grates are engine driven, and have speeds adjustable for ranges up to four inches per minute. Vertical shutters at the feed hopper on the boilers regulate the depth of fire on the grates. The installation operates practically smokeless, except in starting fires. Ashes drop from the gates into sub-chambers, and are drawn off into an electrically driven coal and ash conveyor, which receives and dumps automatically when set as desired and started.

Furnace gases on leaving the boilers pass through a Green fuel economizer with dampers at entrance and exit. This economizer effects 10 per cent. fuel saving.

The engine room is traversed longitudinally by an electric crane of thirty tons capacity.

It contains four cross-compound condensing Allis-Corliss engines each rated at 1,200 H. P., at eighty r. p. m. with maximum capacity of 2,000 H. P. each. They are of special heavy railway type, with twenty-four foot fly-wheels each weighing fifty tons.

Steam is furnished at 150 lbs. gauge pressure and exhausted in a condenser vacuum equivalent to a 24-inch column. The condensing apparatus is of the Allis vertical type, and is independent of the engine.

Adjacent to the main building is a rectangular Barnard cooling tower sheathed with ¼″ steel plate and divided internally into five vertical sections, each provided at the bottom with two ten-foot fans carried on the shaft of an 18 H. P. motor. The fan speeds may be varied by three different motor combinations. The condensing water is delivered to a distributing header 30 feet above ground level. Thence five mains distribute it into drip pipes in the several sections, where the water trickles downward over wire mats continuously fanned by the cool air blast from below. The final temperature of the water is about 85° F.

The electric generators are four 800 K. W. 12-pole Westinghouse compound-wound dynamos with large overload capacity. The field pieces are vertically split and can be slid at right angles to the shaft, giving access to the armatures which are mounted directly upon the engine shafts.

The main switchboard is made up on the panel plan and so fitted with instruments as to record separately all sub-divisions of the power generated.

The station shows great operating economy in practice.

A complete power-house shift includes chief engineer and clerk,

with nine men, five of whom rate only as helpers and oilers. Hence the labor cost is very small.

The power-house records show that the total power-house cost per kilowatt hour delivered to the switchboard is less than one-half a cent.

Distribution.—The system of distribution is a modified plan of what is popularly known as the "third rail" system.

Extending from end to end of the line, on the inner side of each track and along all switches and cross-overs is an ordinary forty pound T-rail, in 60 foot lengths, supported on insulators at short intervals, and with its surface about 4 inches above the working rail and a few inches from it. This rail is bonded at every joint with

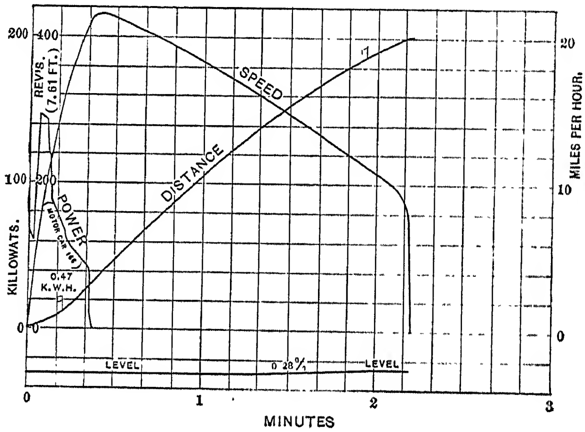


FIG. 7 —Acceleration and Coasting Curve.

double horseshoe bonds to provide continuity of circuit. It is known as the "power rail," it forming one terminal of the electrical system, and is the rail with which flexibly mounted shoes carried on the car trucks make contact.

This rail is divided into sections of varied length, which sections, instead of being left open as has hitherto been the practice, are joined together by switches or fuse blocks so as to make the rail electrically continuous under normal conditions, but with provision for cutting out a section automatically or at will in case of short-circuiting.

Extending each way from the power-house are five feeders carried on insulators on the center of the structure under a housing, the majority of these feeders being connected to the power rail

sections by sub-feeders through circuit breakers at various points. One feeder goes to a connection between the South Side system and the "loop" for emergency, and two of the feeders are used in connection with storage batteries which are placed each at approximately half the distance each way from the power-house to the ends of the line.

The return circuit is made through the tracks, which weigh ninety pounds to the yard, are bonded at each joint, and cross bonded every 120 feet.

There is also a permanent connection between the power rail of the South Side system and the "loop" through a fixed resistance, and cars and trains in passing from one system to the other at times receive current from both stations, and they are also directly connected together at the time of transit through the shoes on cars passing over the gap.

Storage Batteries.—The introduction of the storage battery on elevated work, which is a step in the progress towards high-tension long-distance transmission with local sub-stations for railway operation over considerable distances, was made on the South Side for the first time in elevated railroad practice. The high schedule required, the number of trains in operation, and the consequent heavy demands for current due to quick acceleration and aggregated loads produced a somewhat more marked variation in the central power plant than would occur with less severe transportation demands. The batteries therefore act as equalizers for the central station, reduce the drop of potential on the line, add greater reliability to the power supply, and in some measure carry a proportion of the peak load which is characteristic of elevated practice, where the great bulk of traffic is carried in the morning and in the evening in limited hours.

Each battery consists of 248 cells, "chloride" type, made by the Electric Storage Battery Co., of Philadelphia. Each cell has twenty-six pairs of plates, and they are carried in lead-lined tanks built for twice that number so that the battery capacity can be easily doubled.

Each battery has a capacity of 535 kilowatt hours at the hour-discharge rating, and can easily discharge fully 60 per cent. above this with safety. The nominal charging rate is about one-quarter that of the hourly discharge, but of course it can be increased when necessary. Some addition to the battery has recently been made because of the increased service demands.

The batteries are placed in multiple with the line without any

booster. Their operation is entirely automatic, each one acting both as a reservoir for energy and a regulator of the voltage. Of course, one practical effect is to increase the capacity of the supply system, and in operation the present battery takes the place of one unit at the station.

Car Equipment and Control.—We come now to the car equipment and system of control—the multiple unit—which is the distinctively characteristic feature of the whole installation.

It has been already pointed out that the multiple unit system is an aggregation of transporation units of variable size, each equipped with the power required to operate that unit at a given schedule and under determined conditions, with means for controlling the aggregation from two or more points. This does not necessarily mean

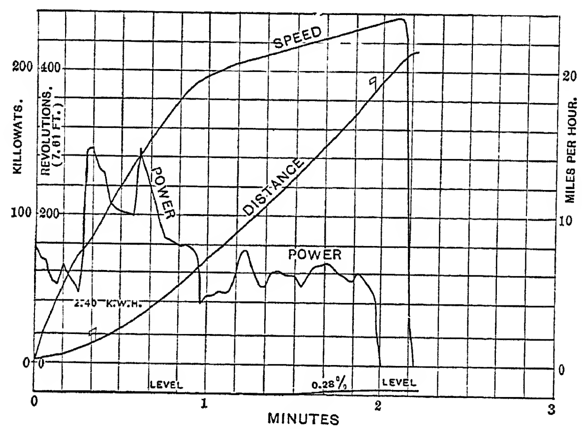


FIG. 8.—Slow Acceleration with no Coasting.

that every car is equipped—that depends upon the schedule and the requirements of acceleration—for the method is equally applicable whatever the number of cars that are equipped with motors or the number of motorless or "train-line" cars which are mixed in with them. For example: A train can be made up of pairs, each of which forms a transportation unit consisting of one motor and one motorless car, so that the train units can be made up of two, four or six cars that is, one, two or three couples, thus averaging one motor per car in use. Three and five car trains can be made up, the third and fifth being a motor car or a train line car.

In any case, two-motor equipments can be put on one-half of the cars, and the balance equipped with a train line so as to get one

schedule, and when it is desired to increase the schedule, motors and a controller can be added to the partially equipped cars.

Of course, the finality of the system on roads with frequent stops, to get the maximum schedule speed, is a motor on each axle, but in a large number of cases, and with pivot truck cars, commercial demands are such that two motors per car is sufficient, and on some service, two motor, or alternate cars only.

The equipment of the South Side road has been made on a mixed plan, 120 cars first being each individually equipped with two motors, then thirty cars with a "train line," but without motors, and finally thirty additional cars completely equipped.

The position and arrangement of the South Side yards, and the running of trains into a Y at one end and around a loop at the other, produces every possible aggregation of cars. Hence for the equipment, in order to avoid head and tail switching, and to permit of this variable aggregation, there was one vital condition, which was that, no matter how trains were made up, like hand movement at the end of any car must at all times mean like track movement relative to the operator, and the system of connections from one car to another must automatically provide for such a result.

This variation of car aggregation, and the further condition that no seat room should be taken up by the motorman, made it necessary to provide each car with a movable cab on the platform such that it could be left open for the free use of the ordinary entrance gate when in the body of the train, and yet be readily closed and afford protection to the motorman when at the leading end, at the same time allowing free passage from one car to another. On each car, therefore, at the right hand diagonal corners the iron work has been removed, and a three part cab constructed, the outer end being a fixture with a drop window, and carrying in the angle formed by the platform the initial controlling mechanism, being the master controller for the electrical system, and the engineer's valves for the air brakes. On each side is a door, each hinged in opposite direction, and folding back one over the other against the header of the car, leaving when in this condition the platform clear, and the ordinary gate in operation.

When used by the motorman, one or both doors are closed, the iron gate swung in place, and a small protecting cab is the result.

Under one end of the car, in place of the ordinary truck, is a motor truck carrying two 50 H. P. (hour rating) standard railway motors of capacity and gearing such as to safely allow the motors

to work up to the skidding point of the wheels with 60 per cent. of the weight of the car equipment and load upon them.

The motors are of the General Electric manufacture, and of the usual Sprague suspension.

In the hood of each car is a controller for the motors, enclosed behind a trap door which can be lowered for ready inspection. The controller is of the multiple-series type, is driven by a small pilot motor, and provision is made for at will or automatically producing a step by step, or interrupted, or periodic forward movement of the controller, and a continuous or interrupted return movement of it to the off position through various automatics connected with the pilot motor and the initial control circuits.

In addition to the current-varying controller, there is a main reverser, likewise operated by the same agencies as the pilot motor, for determining the direction of the current delivered to the motors, and for instantly opening the circuit of the motors in case of emergency.

Inside of each cab is a small master controller or operator's switch mounted on a standard, and fastened to the woodwork of the cab. Through this master controller the pilot apparatus of the current-varying controller and the reversers are governed. It is provided with a movable handle, operating a spring-retracted spindle, which through various degrees of movement makes contact with the reverser circuit and with three determinate positions, coast, series, and multiple. Momentary contacts on these various points give any desired intermediate position of the main controller, which has a stepped movement. In order to maintain the controller at any point, or to keep the governing circuits or train lines energized, the handle of the master controller must be held in position. If the handle is released, whether from accident or design, the spindle instantly returns to coast position, and the controller automatically returns to the off position and cuts off the current, or if the master controller is allowed to go to the center position, the reverser is instantly opened, and the controller then comes to open circuit also automatically.

The arrangement of circuits is such that by the use of a relay and throttle, and the proper inter-connection between the controlling circuits the operator is at liberty to do about as he pleases with the master controller, and can rely upon the main controller operating satisfactorily.

For example: He can go to the series or to the multiple position, or, from the last, reverse movement instantly, and the con-

troller instead of responding instantly operates progressively, the pilot being limited in its movements by increment of the main current to or above any definite amount.

The throttle is set just short of the skidding point of the wheels on a normal track, allowing 15 per cent. adhesion, and absolutely limits the current input to that which is required by the determined rate of acceleration. Any rate less than this can also be effected by proper handling of the motor controller, so that any movements, no matter how refined, are perfectly possible.

This throttle is in the circuit of one motor only, so that it is equally effective whether in the series or multiple position.

Although there is a master controller on each platform, their construction is such that interference with them is difficult, and has never been known to occur. Of course, they could be made removable.

So far, the system described is that of a secondary electric control of a single controller, but by paralleling the relay and other circuits it is evident that the two or more equipments on a single car can be operated, and also that if these equipments are put on different cars they can likewise be operated provided means exist for properly connecting the prime controlling circuits, and ensuring practical synchronism of the different controls and equal work on the different motors. Where the equipments, however, are on different cars, it then becomes necessary to have a "train line" and couplers, so that a governing circuit which can be energized at various points is made up of a train line individual to each car and couplers of some kind between them.

This train line is necessarily an independent line, not being a part of the main motor circuits on any car. It can be energized of course, from any electrical source, but for convenience the main source of supply is the one used.

This train line consists of five wires, perfectly insulated, made into a common cable permanently located in the car, and terminating at each platform in one or more couplers, in this particular case in a pair of couplers, one under each corner of the platform, these couplers being shrouded so as to prevent dirt or rain entering them.

When trains are made up, the train lines are connected by a reversible jumper having corresponding wires, and the system is so disposed and connected that no matter from which corner the connections are made, or how the cars are reversed or altered in sequence, the circuits are automatically established so that like track movement is always assured with like hand movement of the master controllers.

The section of train line in each car is not a part of the normal controlling circuit individual to the control equipment, but is connected with it with switches which enables a severance of the two systems, that is the local car system and the train line, so that no matter how trains may be made up it is always possible to disconnect the controlling mechanism of any train for any purpose whatever.

The practical result of the system is that every aggregation of cars, whether one or more, has identically the same characteristics in the matter of load, capacity, motor equipment, rate of acceleration, etc., as are possible with a single car, and every combination is made without the slightest thought being given to pairing of electrical circuits.

Each car is equipped with an automatic air brake system, supplied by Christensen air compressors, with a reserve tank, and an equalizing pipe running from car to car, the compressors being started and stopped automatically through an air-governed switch by fall and rise of air pressure.

On each platform, alongside of the master controller, is a small engineer's valve, so that from any selected cab the air brakes can be operated with equal facility.

A balance wire runs throughout the train, and is included in the same coupling that connects up the electrical train line, so that when an air governor on any car closes circuit, all compressors start and continue in operation until the last governor throws out. This is to effect equal work on the various compressors, and to maintain absolute certainty of air supply at all times.

If a train should part, three systems of automatics come into play. The reversers go to open circuits, the controllers to the off position, and the air brakes also automatically operate.

If the main circuit fails, all reversers open instantly, and the controllers must come to the off position, which they will do automatically as soon as current is restored, before current can again be put in the main motor.

So, too, if there is an instant reversal of the master controller. The reversers first open circuit, the controller returns to the off or any determined position, then start again, and are instantly arrested on the first contact. Provision is made so that it is impossible to run backward at more than one-half speed from any platform when operating from that platform.

The cars are of course electrically lighted, and are also provided with electric heaters.

For several weeks, on account of lack of equipment, the motors on the equipped cars in the morning and evening hours were subjected to a regular increase of load of about one-third and at times every motor car has been in operation. The economy of quick acceleration for high schedules has been thoroughly demonstrated, and Fig. 7 gives a section of a run which is typical of operation when coasting freely. On this test, with car making fifteen mile schedule, and under the conditions of grade and station intervals on the South Side road, the energy used at the car was about seventy-three watt hours per ton mile.

The accompanying inset, Fig. 5, shows an actual run with existing station distances.

Fig. 6 gives an illustration of what is sometimes preferable practice, particularly in fogs, a quick acceleration to a somewhat lower maximum speed, and then operating motors in series to maintain a constant or slowly diminishing speed to the point of braking.

These form an interesting comparison with the curve shown in Fig. 8, that of a motor car pulling three trailers, which is typical of locomotive car practice on frequent service. It will be noted that the acceleration continues to the point of braking, the most uneconomical method of operation.

A very large number of records have been taken by Mr. Lundie, these running into the hundreds, under all possible conditions of acceleration and all sorts of motor and trial car combinations, for determining the best methods of operation, the highest degree of economy under various loads, and for ascertaining track, car and gear resistances, resulting in a very satisfactory equation with speed and weight as factors. These are conclusive of the benefits of this method of operation, independent of the influence on passenger traffic of high schedule speeds and short time intervals.

The system was put to the hardest test on October 19th, Jubilee Day, and although operating with only 148 cars on nearly twenty miles of total trackage, 240 cars per hour were sent into and out of the loop at Congress street hour after hour, without a hitch. This was done by reversing trains at cross-overs at three or four different points, thus intensifying the car movement where traffic demands were greatest. At times, 65 per cent. of the one track on the loop was covered by cars from three different lines.

On this particular day, when the car mileage was increased about 80 per cent., and with very heavy loads, the central station had six 400 H. P. (standard rating) boilers only in use, with but two men in the fire room, and there was no straining of engines, dynamos or batteries.

As an example of extraordinary duty, the operation during the recent holidays may be cited. During a good portion of the time the central station is reported by the consulting engineers as operating as follows:

Fifty per cent. overload for six hours; full load for seventeen hours, and 74 per cent. load factor for twenty-four hours.

Out of 120 motor equipments designed for individual operation, 119 were in daily operation morning and night, with twenty-eight or twenty-nine trailers, thus overloading the motors one-third, and often these trains, coming out of the loop from two to five minutes late, have made up time before reaching the end of the run, but naturally of course at a loss of efficiency.

The average duty of this equipment is higher than that of any other elevated railroad in the world. Cars have frequently made as high as 290 miles a day for days in succession, and the average maximum of cars in operation for long periods ran to nearly 100 per cent.

Financial, not alone technical, results are a measure of success, and a comparison is therefore in order.

The months of November and December, 1897 and 1898, are the first strictly comparative months.

The road then included "loop" operation, 19.44 miles of track, in 1897 was operated entirely by steam, and in 1898 entirely by the Sprague Multiple Unit Electric System.

In addition to all "loop" expenses there is a rental charge equal to 10 per cent. of the gross passenger receipts of the road. This should be considered really as an interest charge, not as an operative expense.

For these two months with an average of 489,979 car miles on the main line, the comparative table following shows:

(a) Ratio of expenses to earnings, *including* "loop" rentals, taxes and licenses;

(b) Ratio of expenses to earnings, *excluding* "loop" rental, but including taxes and licenses;

(c) Net earnings.

	(a)	(b)	(c)
November, '97, Steam	87.3	77.7	$10,603.80
November, '98, *Electric*	57.3	47.7	39,448.56
December, '97, Steam	83.6	73.8	14,691.69
December, '98, *Electric*	55.0	45.4	45,355.68

The succeeding months show increasing traffic and equally favorable results.

The operating expenses per car mile during November, 1898, on the main line, including and properly apportioning to it everything except licenses, taxes and rental, were less than seven and one-half cents on an average and maintained schedule of fifteen miles an hour, with stations 2,080 feet apart.

So much for the actual results accomplished on the South Side road. The question naturally arises: Have there not been difficulties, and if so, of what character?

Of course there have been, and I should have been surprised, and almost sorry, if it had been otherwise, because it is only through the difficulties incident to the earlier operation of a system of this character that the essentials are fully determined, and apparatus developed to a state of perfection.

It is curious, however, that there have been more troubles with what is classed as "standard apparatus" than with that individual to the multiple unit control. These troubles were, first, with the rheostats, which were of new construction, and later, poor brush terminals, cracked gear cases, and with the earlier type of air governors.

With the specific multiple unit apparatus the principal troubles were with poorly and hastily wound relay coils, too light and unsubstantial construction of auxiliary contacts, and improper jumper construction, causing an occasional opening of the controlling circuits.

Taken all in all, however, the president and superintendent of the road state that there were less troubles than when starting with their compound locomotives, and on the whole the success of the road has been unparalleled in electric railway history where so radical a departure has been taken.

Essential Features of Elevated and Suburban Railway Equipment.—Coming to New York conditions I may say that, based upon the Chicago performance, and allowing for difference of coal cost, the Manhattan road, now operating at twelve and one-half miles actual schedule during time of maximum load, and making about 43,000,000 miles annually, can be operated at over a sixteen-mile schedule at not exceeding nine cents, instead of 11.9, and on the existing mileage this would mean a saving, excluding interest on investment of about $1,250,000 per annum, or allowing interest on investment of about $750,000, to say nothing of any other gains. A seventeen-mile schedule can actually be made with two motor equipments.

In closing, perhaps I may venture an opinion as to the general

features which should characterize a suburban passenger railway equipment. I think it may be safely stated that the first is the use of the continuous current in the motor equipment in spite of the claims which have been made and the results accomplished with alternating current motors, at least so far as we can judge by any present developments.

The problem then is whence shall be derived this continuous currents, and that depends upon distances. For moderate distances, continuous current generators supplying current directly to the line, with or without the addition of storage batteries, is preferable. When the extent of the line becomes at all serious, then it must be considered as made up of a number of shorter sections joined together, each of which derives its principal source of supply from a local station, which station can be driven directly by water or steam power, or by an alternating current from a distant station, using a motor-dynamo combined in a single type of machine, the rotary converter, or joined in the form of a directly coupled set, the dynamo end being for continuous current and the driver a synchronous or induction type of motor.

Generally the sub-station should be supplemented by a storage battery, to take care of fluctuations in the load, to even up the duty on the sub-station and as far as possible at the central station, and to take care of some portion of the peak load caused by abnormal variations in the aggregate service at different times of the day.

Of course, with the storage battery comes the necessity of a means of some kind of automatic regulation; there are various methods, but I will not enter into them here.

Looking forward, however, to a perfectly assured future of a heavy service over considerable distances, I may state that the general equipment of such a road should generally involve the following essentials:

High potential alternating current transmission from one or two well placed central stations, with or without static transformers.

Motor-dynamo sets, or rotary converters at a number of conveniently placed sub-stations, to convert high pressure currents into continuous currents of about 600 volts pressure.

Storage batteries of quick charge and discharge capacity, generally at the same sub-stations as the motor converters, to equalize their duty and to prevent sharp variations in the general plan as well as the sub-station.

A system of feeders and main conductors.

A power rail or trolley wire supplying continuous current, but ordinarily without any switching of currents.

Individual transportation units with a multiple unit control, so that combination of cars without regard to sequence or end relation can be made up at any portion of the line independently, and controlled from any selected point.

DISCUSSION.

MR. JOHN B. BLOOD:—I would like to ask the maximum acceleration obtained in either pounds per ton or feet per second.

MR. SPRAGUE:—I cannot answer definitely as to present practice, not having been there for months. I have seen a number of records showing an average mile-second rate up to time of cut-off, and for the first seven-tenths of speed, before working on the motor curve, a one and a half mile-second rate.

MR. BLOOD:—Do you get as high as 100 pounds per ton?

MR. SPRAGUE:—Yes, we do that quite easily.

MR. BLOOD:—I know you can, but I was wondering if you do.

MR. SPRAGUE:—Yes, I think so but I haven't the records with me. I think very likely there are some gentlemen in the room who have been making tests on the road who can answer that question better than I can. We have gone up to the slipping point of the wheels, which would be 300 pounds for each ton on the drivers with normal condition of track. We do not force the machines to quite that extent. Being a two-motor equipment with double trucks, we average 61 per cent. on the drivers, and that does not vary with the load more than about three per cent. either way. Fifteen per cent. adhesion gives 300 pounds to the ton if everything were on the drivers. We can certainly work to over one hundred and fifty pounds actual pull.

MR. BLOOD:—I notice some of the best tests in braking give as a maximum about 200 pounds.

MR. SPRAGUE:—Of course, in braking we have every wheel in operation, and also all our weight. If we should work up to the slipping point, we would have 180 pounds, provided the track is in good condition. We do not work quite so high, for that would leave no margin.

MR. F. V. HENSHAW:—I would like to ask Mr. Sprague how he takes care of the possibility of accident to the small motor. Suppose you were running and the master controller was turned off, and for some reason or other the main controller does not turn off. Something happens to the small motor; what takes care of it then?

MR. SPRAGUE:—That could not well happen on all the cars at once. There is no possible excuse for small motors being made so that they are not reliable. This particular controller will handle two 50-H. P. motors, each of which is guaranteed to work up to 100 H. P. It is not a very large piece of apparatus—in fact, about the size of an ordinary street car controller.

To operate one of these requires an eighth of a horse power

pilot. This pilot runs cold, because it only operates spasmodically. It has only a fraction of the duty a fan motor of the same rated capacity has.

But let us assume the possible condition of a jammed controller. Nothing disastrous will happen. If we wish to open the circuit, we can do it instantly on the reverser without regard to the main controller, and, having once opened, it is impossible for that particular reverser to come back until its controller has been returned to any determinate position it is set for. The reverser circuit passes through split paths. The initial path is through a contact carried on the main controller, which when the controller has advanced one step is entirely cut out, but a supplemental circuit dependent on the current in the reverser circuit itself has meanwhile been made, which maintains that circuit although the original path is open. If this supplemental contact for any reason opens, there is no method of again making the main circuit on that car until that main controller comes to any required position, generally the coast or first contact position. Of course, if there are three or four cars in a train, one equipment can be entirely cut out, and the schedule speed made by forcing the balance of the motors. It is a matter to which we pay little attention in practice. This possibility was one of the first things which occurred to us, but it was met by affording two absolutely independent methods of opening the main circuit, one preferably power-driven and the other automatic, the operative relay circuits of which are electrically interconnected, so that when once the main circuit is opened it cannot be again closed except under perfectly safe conditions. It would, of course, be a serious objection if provision had not been made for this very possibility.

MR. HENSHAW:—Then the result would be, if a pilot motor failed it would simply cut out that one equipment?

MR. SPRAGUE:—Yes; but ordinarily little attention would be paid to it until arriving at the yards. The guards and motormen very soon get used to the equipment. If the controller does not move, they know something is up, and when they pass the dispatcher they report that on a certain car the controller is not operating. The train does not stop; it goes on. When the car is in operation, one can open and close the main circuit breakers without any other effect than simply throwing additional load on the balance of the equipment, the counter-electromotive force of course protecting the machines.

A MEMBER:—There is one point that Mr. Sprague has not touched on, I think, and that is the cost of maintenance and operation of this intricate automatic mechanism, and the cost not only at the end of one year, but at the end of ten years.

MR. SPRAGUE:—Wherein lies the so-called intricacy of system? It is largely a matter of imagination, as can be readily seen by the most casual inspection of the actual apparatus. Let us consider it for a moment in detail.

First, as to motors, we can go back to street car precedents. There

is not a car running in the city of New York, and few in the United States, amounting, perhaps, to 40,000, but that has two motors and two main controllers. The motors are identically of the same character and general construction as those used on the South Side Elevated Railroad, and differ only in size. Certainly so far as depreciation of motors and gears are concerned, it should be less than on ordinary street cars, because the motors are out of the mud and they are better protected, and the duty is less severe, for they do not stop and start so many times.

I have heard this bugaboo raised many times, but really it is hardly serious enough for me to pay any attention to it, nor indeed for any one else who is familiar with modern motor construction and use.

There is only one main controller on a car, instead of two. The ordinary working parts, that is, of the model before you, are identically the same as those of an ordinary controller. Consequently there is nothing so far which introduces a new factor, and whatever the practice is on street railways is certainly good on an elevated or suburban road.

As to the pilot motor and its limits. What, may I ask, is the depreciation on a fan motor which runs oftentimes 24 hours a day and in the most out of the way and forgotten places? The construction of this pilot motor is practically the same, only better. There is nothing remarkably unique about it. The contacts which interconnect its circuits carry the same current as the master controller and the train line and jumpers; the fraction of an ampere.

The master controller has two moving parts, a removable handle and a cylinder formed of two castings, and some contact fingers of an ordinary type.

The relays could not well be simpler. They are plunger magnets, the cores carrying loosely mounted self-adjusting copper disks which impinge against rigid contacts through which are made the pilot motor circuits. Surely one cannot speak seriously of great depreciation in apparatus of this character.

The wiring of a car is actually simpler than on an ordinary street car, there being less work and less material. The train line is of permanent character, much like that of the lighting circuits, and there is only one set of main motor cables.

As to the jumpers, I have already said we have had some trouble with the breaking of wires, caused by mistakes in the early practice of making up the cables. Practice, however, has taught the trick of making these right, but how they are really constructed is a matter I prefer not to discuss at present. I think it may be fairly said that there is less liability to trouble with them than with an ordinary air hose.

Speaking generally, there does not begin to be the complication there is in an automatic air brake system, and yet I do not hear any one inveighing against the practicability of the latter.

As to ordinary inspection and care on the multiple unit system, one man can easily look after the master and main controllers and circuits of 25 or 30 cars.

Mr. Blood:—It seems to me the argument has been motor for motor, and controller for controller *per se.* Would it not necessarily be a fact that if you had ten motors and ten controllers that you would be liable to have proportionately more trouble than with four motors and two controllers in proportion to the number of pieces of apparatus?

Mr. Sprague:—Possibly I am more of a railway than an electrical engineer. To my mind there is something more to be sought in railroading than the saving of a pound of coal or a dime in inspection or repairs. It is to catch the passenger's nickel, and it does not take much variation on a road to determine its success or failure. If you put the abstract question of whether it is cheaper to take care of one motor with one controller than several, that is, of course, in general true. It would cost less perhaps to have one chair in this room for everybody to sit on, but it would not be so convenient. You cannot operate a railroad under a flexible system which gives you absolute independence in train units and train intervals unless the cars stand on their own bottoms. They cannot be pulled around by the head by something else. To borrow a phrase, we cannot much improve on the Creator. A caterpillar's legs were not put under his head with instructions to drag his body behind him. He gets along, not on all fours alone, but on all multiples.

The proof of the pudding is in the eating thereof. Despite all the dismal prophecies of failure—and there were, as you are well aware, plenty of them—we have been running sixteen thousand to twenty thousand miles a day, and performing a service unequaled in electric railroading.

There seems a curious misconception of the practical requirements of railroading, a tendency to make it simply a problem of moving a fixed length of train a certain distance. The railroad man has not simply a clear and exclusive right of way from one point to another with the necessity of all people to come, because if he has a good thing another man will come along and build another railroad alongside of him. Consequently the manager who proposes to keep the passenger has got to give him the utmost facility of travel, the least station wait, the quickest transit, including that wait, from the time he gets on the platform until he gets to his destination, and it is that frequency of service which is absolutely vital to successful competitive railroading. No one would think of operating on Broadway or Sixth avenue a six-car train at six times the interval of their present cars. Some day, because of the congestion of traffic, they will probably have to operate two cars together, otherwise a longer unit, but maintain the same characteristics of acceleration.

Mr. C. W. Rice:—I should like to inquire the relation of the storage battery to the success of the multiple unit system.

Mr. Sprague:—It is not necessary for the success of the multiple unit system. There are a good many railroads running independent cars without a storage battery. We all know that in any

system of transmission of power the more even the output the better it is for the central station. The South Side road ran for a long time without any storage battery, which was not proposed as a part of its original equipment. The central station was laid out for a larger equipment than was first installed.

The road actually required 145 to 150 cars in operation, including those on the loop, but not including cars on reserve, which ordinary conditions of painting and general repairs determine as at least 10 per cent., and some think even more, of the total equipment of a road. Only 120 cars were equipped, and the road ran under these conditions until finally there were about 150 cars, including 30 partially equipped cars, in operation, more than there was central station capacity for. Consequently they finally concluded that the quickest way to get additional capacity was to put in a storage battery, which would help to equalize the load and to take a part of the peak. I would say in general, however, that the introduction of a storage battery is advisable on any elevated or suburban road, and, in fact, on any electric railroad when its capacity is to be increased.

No one here should misunderstand the position I have always taken with regard to the storage battery. For a long time it was an impracticable piece of apparatus, but when people got tired of fighting patents, and, with a fund of increased experience, settled down to build a practicable battery—realizing that its proper function for railroading was, as I have time and again stated, primarily for regulation, that is, for quick charge and discharge, and for use on peak loads for short time duty only—then it became a safe and advisable adjunct to a railroad when put in under proper guarantees.

The question about the storage battery seems to have been asked because of the impression that on a multiple unit system there is necessarily a large current input on a train, which system *per se* as ought to be perfectly evident, has nothing to do with it, because properly it is simply a semi-automatic system of control which permits of the aggregation of a number of transportation units. That aggregation does not fix the rate of current input, and for any ordinary schedule, no matter what the weight on the drivers, a less than the maximum rate of acceleration can of course be adopted. The speed of the main controllers is not a fixture. The current input is determined by an adjustable throttle which, whatever the carelessness of the motorman, permits of any predetermined slowness in the rate of acceleration, and whatever the maximum rate allowed, it is still possible for a motorman to adopt any lower rate at will. In fact, finer and more even gradations of current input is possible where dealing with smaller currents on individual main controllers than where the whole is aggregated in one large one, as determined by the practical limitations of construction.

MR. BLOOD:—I am very well aware of the schedule and the frequency with reference to the operating, and also the fact that

if you have a system which operates at 50, 60, 70 or 80 per cent. of the income, that it pays to do everything to increase the traffic with a given plant as long as the ratio of the percentage increase in receipts to the percentage of increase in the operating expense total is not less than the ratio of operating expenses to receipts. But the point is, do you not claim a great many things for the multiple unit system, as a system, which accrue to the system, not on account of itself, but on account of the increased speed which you obtain? For instance, on the Chicago South Side you have ten motors of 50 H. P., which makes 500 H. P. If you put the same amount of power on the front car in four 125 H. P. motors you can get the same pounds per ton and the same acceleration and same speed.

MR. SPRAGUE:—How are you going to do it? How actually make use of the power available.

MR. BLOOD:—For instance, the present Metropolitan West Side has two 100 H. P. motors on the front car, and they have made a schedule speed of 12½ miles an hour. They never slip the wheels under ordinary acceleration, and they run up to 55 or 60 pounds per ton. If you put on four motors of 125 H. P. you will get the same torque, the same pounds per ton weight of train as you get now with ten motors, and you would have therefore the same schedule speed. I believe the South Side runs on a little less than 15 miles schedule speed.

MR. SPRAGUE:—They run at 16½ miles when they have to.

MR. BLOOD:—But I mean the regular schedule on the road is a little less than 15 miles, and the regular schedule of the Metropolitan and Lake street roads with the two motors, which handle three cars, is a little over 12 miles. It seems perfectly feasible if you put four motors and increase the capacity of each motor 25 per cent. that you could get the same schedule as you do now with the South Side trains.

MR. SPRAGUE:—You seem to forget that when you concentrate the capacity of motors, be it 500 or 600 H. P., whatever you please, on one car of a five or six car train, you have not the same ratio of weight on the drivers, and consequently you cannot get the same effective pull. That is impossible, unless you pile pig lead into the car.

MR. BLOOD:—Of course the same weight is not on the drivers, but if sufficient weight is on the drivers to get the pounds per ton which you get now in your schedule, sufficient is enough.

MR. SPRAGUE:—I think I will "stand pat" on the proposition that for all round duty you cannot count on more than 15 per cent. adhesion of steel against steel, and that there are many times, in fogs and other conditions, when you do not get that. It is always advisable to have a reserve. You should be able to slip the wheels even on the South Side road, as we sometimes do, with 62 per cent. of the total weight of the drivers. If you should take a locomotive car and put on it four 125 H. P. motors, you can slip the wheels as long as you please and you will probably not

break down the motors, but you do not reach the practical limit of acceleration which is comfortable. I care not how fast it is, so long as it is done evenly, there is no rate of acceleration possible even with 100 per cent. on the drivers, which is not perfectly feasible so far as passengers' comfort is concerned, but it must not be by jumps, but with a controller that is properly built, graded and regulated.

MR. BLOOD:—I perfectly agree with that statement, and I also do not wish to be understood as an opponent of the advantages of the multiple unit system. But what I do wish to bring out is that the point at which the system gives advantages on account of its increased acceleration is far above that of any system that is in operation now. I worked at a multiple scheme in connection with some propositions in Berlin and Vienna, and it might be interesting to know that the scheme proposed by the German companies was with a locomotive at each end of the train.

MR. SPRAGUE:—I think quite likely I can tell you something about it.

MR. BLOOD:—And the chief advantage of the multiple system is the advantage of the splitting up of the train, and not so much at the present time the advantage due to acceleration, because the point is not reached in the present schedules where the advantage will show up.

MR. SPRAGUE:—I quite agree with you about splitting up trains, and I think I said quite clearly that I considered the question of coal economy, which for any given schedule is primarily affected by the rate of acceleration, a thing of less importance than independence in determining lengths of train units and train intervals. The higher schedule speeds for all combinations are, however, only possible with the high acceleration, and hence necessitate high ratios of weight on drivers. I must, however, repeat the statement that for any given high schedule the system which gives the highest rate of acceleration is the cheapest system to install in total first cost, as well as the cheapest to operate. It costs anywhere from \$200 to \$250 per kilowatt for the energy delivered to the shoes of a car. It costs from \$15 to \$20 per H. P. for the equipment put on a car, including every detail on it. I am speaking in a general way. Therefore, if you can save 1,000 H. P. in a large central station you can afford to put a good many thousand H. P. on the cars, and besides you are going to gain a good deal else by doing it.

Referring to the Berlin proposals, it has been only comparatively a few days since I received a letter from possibly the German firm you referred to. It was quite explicit as to the plans hitherto considered. Their plan of operation—and they are somewhat in the air about it—was to operate four-car trains normally with two dead intermediate cars and one locomotive car at each end, each motor car having four motors, the motors to be worked in two groups, two being permanently connected in series, and these two series groups worked in series and multiple; that is, on a four-

car train, eight motors, every pair maintaining a fixed relation. The main current was to be carried from one car to the other, and a hand control provided for all motors at each end of the locomotive cars. In stopping it was proposed to use the forward car alone for an electric braking system. Realizing, however, that there are times when the traffic would require more than four cars to the train, they were contemplating a possible method of combining two of these four-car eight-motor trains into an eight-car train.

The difficulties experienced were leading them to inquiries into the multiple unit system, which is the straightforward logical development, and in every way simpler and more effective.

Now I have had a modicum of experience in electric railroads, and I am quite ready to let some other men try all sorts of alternative combinations. Evidently these engineers recognized the fact that they had to use a large proportion of the weight on the drivers, large motive powers, and hence distributed motors, and that is what they are proposing to do. That happens to be an official statement of facts from the firm which has the contract under consideration.

MR. BLOOD:—The reason that they were to use the two ends of the train was that the German government specified that the control must be from each end of the train to obviate shifting the motor car at each end of line. In reference to that, the first road which the Siemens people were to try it on, which was the Wansee road, at the Wansee end they did not have the opportunity for switching. I figured out a scheme whereby they could; but the German government decided it could not be done, and so they wanted trains built that way. I do not think that they considered the distribution of the motors, and the reason they would not allow braking on the rear car was because they were afraid that the train would double together in the middle.

MR. SPRAGUE:—In other words, they ran across a lot of difficulties the moment they attempted a combined locomotive car system. One of the goods things the German government does is to put down certain restrictions. Really the broad issue is between a secondary control and an attempted control with main circuits running from one car to another. I am quite content to rest on that issue.

MR. H. WARD LEONARD:—It seems to me that one of the most important points in connection with the question of elevated practice, as has been clearly brought out by Mr. Sprague in his remarks and by many others heretofore, is the fact that a very rapid acceleration is a necessity, and that having stored up in the train a very large amount of energy represented by that acceleration, it becomes necessary with the practice which has been described to waste that energy on the brakes, and it appears to be of the first importance for the future development of such systems as require such rapid acceleration and stops in such distances as 2,000 feet or so, as in elevated practice, that a system should have

some means of saving a large percentage of the energy that is to-day represented by the waste upon the brakes, and I should like to inquire whether there is anything for this purpose that is in mind, and whether I am not correct in believing that both the maximum current and also the total energy which is required by the acceleration—the output of the central station—would not be very much reduced if a large percentage of energy could be restored when the car was brought to rest? Would this not result in a very great decrease in the capacity and cost of the plant which Mr. Sprague has very forcibly illustrated as being very high in relation to the horse-power cost of the car equipment? I quite agree with him that thus far a great deal of time has been spent in trying to save a few dollars on the motor equipment when thousands of dollars are spent without much thought or care in connection with the copper and the engines and generators and storage batteries, and that more economical arrangements, as regards the use of energy on the car, warrant a very much higher price for the apparatus on the car. I should like to inquire as to the question of the energy wasted on the brakes, and whether it is not a very large factor in the problem.

Mr. Sprague:—The maximum speed at which a train is braked is what determines the amount of energy thrown away, and we reduce the kilo-watt hours per car mile by keeping that maximum speed as low as possible. On the South Side road our maximum speed is often only 50 per cent. higher than the schedule. We actually do a great deal of coasting. On many runs the current consumption at the car shoes is only 1.55 per kilo-watt hours per car mile, or from 70 to 75 watts per ton-mile under the conditions there existing. I have, in common with all others who are interested in this sort of subject, considered the return of the energy that still remains in the car at the time of braking, to the line. Of course there are quite a number of methods of doing it. Mr. Leonard no doubt has one in mind. I have had several, and in experiments which were tried on the 34th street branch of the elevated in 1886 and 1887 I used shunt machines, and weakened the field to increase the speed, and in slowing down strengthened the field to send current back to the line. That brought the speed down comparatively low. Then the current was thrown on a local rheostat circuit, and the train stopped without any mechanical brakes. But the series motor has certain advantages, one being its tremendous overload capacity, and others its speed and commutating characteristics. These have led most railroad engineers to use it for the actual conditions of railroad practice, and to abandon the project of putting current back into the line.

Coming back now to the question of schedule speed, high ones, with stations only a short distance apart, are only possible by using a high rate of acceleration, and it is impossible to get it except with high weight ratios. Take, for example, the Manhattan road in this city. Its stations average a third of a mile apart. It is making now 12½ miles actual schedule during the time of maxi-

mum load, averaging its entire runs. On Sixth avenue below 50th street and on the lower part of Third avenue its schedule speed sometimes gets down to 11 miles per hour, although the average is brought up to 12½ miles. It is possible on that road to make a schedule of 17 miles with only two motor equipments per car, although that is pretty nearly straining the limit, but it is quite practical to make over 16 miles, in other words, to bring Harlem abreast of Central Park; that, too, without exceeding the present maximum speed of trains, and with a reduction of the strains on the structure, which has concerned our city officials a great deal lately, but which does not trouble most of us who travel on it. It is possible to exceed 16 miles schedule with only about 25 or 26 miles maximum speed, at not exceeding nine cents per car mile total operating expenses, as against 11.9 or 12, their present cost. Since they make about 43,000,000 miles on their present service; that means a saving of about $1,300,000. I do not know what their equipment would, or, rather, will cost; but after paying a very fair interest on that cost there could still be a satisfactory surplus to the good. All this, of course, is on their existing passenger service, without regard to what it might become with an improved condition of operation.

Mr. A. H. Armstrong:—I would like to ask Mr. Sprague if the rate of acceleration he is using on the South Side elevated is demanded by the necessities of the schedule speed he is making there; that is, if the multiple unit system is needed for a schedule speed of fifteen miles per hour with stops a third of a mile apart.

Mr. Sprague:—It would be possible to make that schedule with fewer motors and more concentration. They could not, however, make the schedule which they will be driven to. Remember, Mr. Armstrong, a road has not always got its path cut out as its representatives would like. You have lately been a somewhat strong advocate of an increase in the rate of acceleration. You have published a number of curves which show the economy of that method of operation. I am quite content to accept some of them as reliable and as authoritative. There will be, at times, conditions of track, of train congestion, and delays in coming out of the loop or getting away from stations, such that it will be necessary to call on all the reserve power in a train, and to force the motors to the limit of capacity and wheel adhesion. Referring to the Metropolitan road of this city, somebody once made the remark that it spared nothing in expense to ensure continuity and certainty of service. That is good engineering and sound commercial sense. That you shall get your passengers through, and safely, is the first requirement. That you shall get them through at the highest rate of speed that you can practically, if you are in competition with another road, is a second one. There were a good many predictions of failure of the South Side road. Possibly you remember them. The company which you represent refused absolutely to take any responsibility in connection with it. It was willing to sell me 240 motors and a good deal of other apparatus, amounting

to a considerable sum of money. But its orders were strict to its engineers that no responsibility for performance other than for guaranteed H. P. should be entered into. I would a little rather not mention some of the incidents attending the putting in of the South Side equipment, but I am free to say that very cordial predictions of absolute failure were made in respect to it.

MR. ARMSTRONG:—Was a time limit set?

MR. SPRAGUE:—No, thank you, not much. Twenty-four hours were given after the rheostats which I bought failed me, resulting in a burned-up car on the road. I think that I stated that we had more trouble with that which is sold as standard apparatus than we had with the apparatus of the multiple unit system, and that trouble is not finished yet, as, for example, on such a simple thing as gear cases.

MR. ARMSTRONG:—That constituted 90 per cent. of your apparatus.

MR. SPRAGUE:—The apparatus we bought in various ways.

MR. ARMSTRONG:—You will naturally expect that 90 per cent. of your trouble would come from outside apparatus, as you stated that it constituted 90 per cent. of the whole installation.

MR. SPRAGUE:—No. I am not speaking of the money amount. It is a good deal more. But I am speaking of the physical troubles —the things which would cause delay and worry. On the first day I started, with twenty cars, seventeen were suddenly taken in because I saw one car going down the road in flames. The trouble was that too thick German silver strip was used in the rheostats, which were not of my own manufacture. Where it was bent around an angle it was fractured; they open-circuited, shot out a flame and set fire to the car. I was worried for a little. I pulled off seventeen cars and kept three on, and helped boost a locomotive and train around a curve, but this trouble was rectified.

But temporary troubles characterizing the early development of a new system are in the nature of children's diseases, soon discarded for man's estate.

You, Mr. Armstrong, and every other engineer interested in serious electric railroading, must sooner or later come to the unqualified endorsement of the multiple unit idea. Please remember that prophecy.

Already your company, as well as others, are swinging that way, as is evidenced in the former's April Bulletin on four-motor equipments for pivot truck suburban cars, wherein the advantages of high tractive effort and quick acceleration are set forth, four motors are recommended instead of two of the same aggregate capacity, and the efficiency and relative cost of maintenance are stated to be about the same.

What are the new electrical and commercial conditions which, when the aggregate of traffic makes necessary the grouping together of such cars into trains, a time when the demands are surely no less, lead to a reversal of engineering conclusions?

Again, for train operation, two 4-motor locomotive cars, with

synchronous control, have been recommended more than once, and what is this but a mongrel kind of multiple unit system?

It is impossible to stem the advance. The locomotive car, as well as the electric locomotive pure and simple, is doomed for the class of electric railroading we are considering.

I think I may fairly say that I have not recorded many failures in prophecies on electric railroading, and I have been making them for sixteen years, during which I have never hesitated to back a prophecy with every dollar I had, and also what my friends saw fit to add.

MR. ARMSTRONG:—I would like to ask another question of Mr. Sprague.

MR. SPRAGUE:—I am a good subject.

MR. ARMSTRONG:—You spoke of the facility with which you could make up a train with a multiple unit system; that any car could be put in any place in the train. I want to know how they manage with the smoking cars in Chicago, whether you keep one car there as a smoker or whether you can use any car as a smoking car?

MR. SPRAGUE:—On the South Side road certain cars are marked smokers, and used as such.

MR. ARMSTRONG:—They occupy a certain place in the train?

MR. SPRAGUE:—I don't know what their present practice is. Perhaps Mr. Shepard can say.

MR. SHEPARD:—One end or the other.

MR. SPRAGUE:—I hope the time will not come in New York when cars will have to be provided for smokers.

MR. ARMSTRONG:—I simply want to bring out the point that you cannot make up a train with utter disregard of any car constituting the train; that is, if smoking cars are used they must occupy a given position in the train and some care must be exercised in making up the train to see that the smoker shall occupy a given position.

MR. SPRAGUE:—I do not mean that if you had a parlor and a baggage car and wanted to keep them in a certain order you could change their character. What I did wish to emphasize was a condition of actual practice, and the fact that so far as control is concerned the end relation or sequence of cars is a matter of indifference.

The South Side Elevated Railroad has a loop at one end, an open ended relay at the other, and a yard somewhere between from which cars can go out in either direction. It is therefore absolutely certain that as cars are made up into trains, and as they are inspected or repaired, they get mixed up, that is, it is impossible to maintain any fixity of relation between them. To-day, for example, the motor ends of two cars may be similarly headed, but to-morrow one of them may be reversed and another car introduced between them, and so on. Curiously enough, this fact seems to have been ignored by every one of late who has been attempting to devise a multiple unit system.

The yard man who makes up a train is not an electrical engi-

neer, nor a doctor of physics. He does not carry around a kit of testing instruments, nor a book of diagrams, but oftentimes amuses himself by hammering the track with a jumper, or in making unquotable remarks. Nor is the motorman a scientist. What they both must know is that when a train is made up, and the handle of the master controller is moved in a certain direction relative to the platform, that that motion is followed by a certain corresponding track movement, and with the least possible thought or calculation on any one's part.

Mr. Armstrong:—I think you rather digress from the point I was trying to emphasize; that is, if a train consisted of a motor car and three or four trailers, the motor car would occupy nearly the same relation to the train as the smoking car does now, and the trail cars would be in the same condition as your other cars.

Mr. Sprague:—In other words, you would subordinate the road to the necessities of the smokers.

Mr. Armstrong:—No.

Mr. Sprague:—As a matter of fact, they run the smokers in that particular case at either end of the train.

Mr. Shepard:—The smoker cars are distinctly marked.

Mr. Sprague:—Of course. I expect arguments against the multiple unit system, even if they must be oftentimes trivial. I cannot hope to have everybody agree with me, but I find a good many who are coming that way as fast as their dignity or associations will permit.

Mr. Armstrong:—I was asking for information, I was not arguing.

Mr. Blood:—In connection with the question brought up in reference to the return of power to the line, I would like to bring up a point which came rather curiously in figuring on a road. It was a road having a constant 5 per cent. grade. I said to myself, here is a good chance to figure on a system of putting power back into the line. There was only about fifteen per cent. of the whole road that was level. In the scheme I figured out I found that, owing to the fact that the efficiency doubles on itself—that is to say, in putting the power into the train you could not get greater than 70 per cent. efficiency from the line to the rail (that is a good high efficiency under ordinary running conditions, not including the stops); if you get 70 per cent. that way and 70 per cent. the other way, the most you can save is 49 per cent., and I figured out in this case, taking the whole thing into account, that the amount of power saved, even though we were going to use water power with auxiliary storage batteries, that the interest on the extra expense would not equal the amount saved. If you remember, in connection with this question, on one of the diagrams which Mr. Sprague had on the screen here, the braking point is much less than the maximum speed, and when it is remembered that the energy varies as the square of the speed, and when it also is remembered that you must take something less than 40 per cent. possibly saved of the total, figuring out the amount of energy

that is in the brakes and the amount of energy that could be saved in the brakes, it will be found that it is an insignificant amount of the total energy used—something less than 10 per cent.

MR. LEONARD:—I think that it is a little out of the line of discussion to debate a point of this nature; but I will just say briefly that I think the last speaker has made a great error in assuming that if you did restore energy to the line the proposition would be true that it would be an economy to operate at very high acceleration and then coast; because the entire argument in favor of coasting as an economy is based on the proposition that you cannot restore energy to the line, and if you could operate with a system which did restore energy to the line the result would be that you would avoid these very extraordinary peaks of energy and also reduce greatly the capacity of your plant and the amount of energy in kilowatt hours that is used. Of course, it is entirely correct that you could not save more than 50 per cent. That is quite readily granted. But I think 50 per cent. is a great deal.

MR. SPRAGUE:—Fifty per cent. cannot be saved. It is impossible.

MR. BLOOD:—Fifty per cent. is the theoretical limit.

MR. SPRAGUE:—You have not only got the train under way, but you have to carry it over the road. What you can put back on the line is actually measured by what the speed of the car is at the point of braking. The quicker you get under way, the less the maximum and the braking speeds.

MR. LEONARD:—Your speed should be the highest when you put on the brake, if you can restore energy to the line.

MR. ARMSTRONG:—In this case the duty on motors would be double, and the first cost of the apparatus per car, instead of \$15 to \$20 per kilo-watt would probably be \$30 to \$40.

MR. LEONARD:—If the cost of the engines, generators, copper and batteries, amounting to over \$300 per kilo-watt, is cut in two, you would have a pretty big saving in the first cost, in addition to the saving in operating cost.

MR. SPRAGUE:—There is a field for somebody's energy. I have been trying for fifteen years to find a practical method. I have never found one which would warrant the expense. The conditions of railroading are arduous. The speeds are variable, they are not constant as they are in certain classes of power service. I must confess that on railroads power return has generally been a failure. I have given up much hope of returning energy to the line, that is, from a commercial standpoint. It is possible from a theoretical one.

MR. LEONARD:—I should like to ask Mr. Sprague if he can give us any information, whether he is at liberty yet to give information, as to the methods by which he obtains the end to end turning of the cars without confusion.

MR. SPRAGUE:—I should rather be excused. It is a point which has generally been overlooked. Of course it lies in a fundamental system of connections. It is scarcely a thing which I can hope

to keep to myself; at the same time I would rather do so for the present.

Mr. Blood:—I would like to have, as a matter of record, what speed it is thought we will have to resort to in multiple units to get a higher acceleration. According to my figures, I place this schedule speed at about 20 miles per hour with ordinary distance between stations, 2,000 feet.

Mr. Sprague:—You mean what is possible?

Mr. Blood:—No. When it becomes necessary to change from the locomotive system to the multiple unit system in order to get the schedule speed.

Mr. Sprague:—I cannot answer that off-hand. It is simply a question of kinetics. It depends on grades, curvature, distance between stations and length of train. As I said a moment ago, there are a good many questions involved besides schedule speed, questions of flexibility of service, distribution of weights, strains, etc. It is really a comprehensive engineering question on any road. When a man starts out he should determine what he wants, and then adopt the most effective method of getting it.

The President:—If there is no further discussion a motion to adjourn is in order.

On motion the meeting adjourned.

APPENDIX.

Chronology of Modern Electric Train Operation from 1880 to 1899.

1880.—Edison built and ran at Menlo Park an electric locomotive, and subsequently designed some others.

1883.—Daft at Mt. McGregor ran the Ampere, pulling one car, and Field, at Chicago, the Judge, also pulling one car.

1884–5.—Vandepoele at Toronto, and later in 1885 or 1886 at Minneapolis pulled trains of cars with an electric locomotive.

1885.—Daft, at Baltimore, operated a locomotive and trail car, subsequently increasing the equipment, and on the elevated road pulled a train with an electric locomotive for experimental work.

December, 1885.—At Society of Arts, Sprague stated some of the possibilities on the elevated railroad, and pointed out the advisability of putting motors under each.

1886.—Sprague built the first locomotive car. This was intended for experimental work on the elevated road, but was abandoned before the motors were completed.

1886.—About this period the Rhode Island Locomotive Works, under direction of Bentley & Knight, designed a locomotive for rapid transit train operation, but it was not built. About this same time Stephen D. Field designed an electric locomotive for the same purpose.

1886–87.—Sprague operated a standard elevated railroad car with two single reduction motors, axle centered, and with one end spring supported from the truck body, on the 34th street branch of the Elevated Railroad and also pulled a trail car, and prior to this, a platform car with the same motors in the Durant Sugar Refinery on 24th street, New York. This was followed by the Richmond equipment, the beginning of the modern development

November 4, 1890.—City and South London road opened. Originally designed for cable. Light trains operated by electric locomotives having two gearless motors with the armatures rigidly mounted on the axles of drivers.

1892.—Sprague, Duncan & Hutchinson designed, afterwards building it, a sixty-ton electric locomotive for experimental work in connection with the North American Company. It was not put to use.

February 4, 1893 —Liverpool Overhead Railway. Operates two-car trains, each car having one motor disposed at the leading and back ends of the couple, the two cars being kept together as a unit. Hand control at each end.

Spring of 1893.—Under the general supervision of Mr. W. E. Baker, assisted by Mr. B. J. Arnold, in charge of the steam plant, and Mr. Charles H. Macloskie, in charge of the car equipment, the Intramural Railway was constructed at the World's Fair. The General Electric Company were largely interested in this enterprise. Four-motor cars, with hand control, were used to pull three trail cars, this plan of distributed motors under the passenger car having been advocated by Mr. Baker in opposition to the general opinion then in favor of electric locomotives. The third rail supply with the flexible sliding contact shoe, was here used for the first time, and the road may be said to be the first real practical train operation on any serious scale in this country.

November 3, 1893.—The General Electric Company's engineers in a communication to Colonel Hain, general manager of the Manhattan "L," recommended eight car trains to be pulled by a single forty-ton four-motor car, guaranteed an increase of 14 per cent. in schedule, and stated that the motor car could pull thirteen-car trains as easily as present steam locomotive could pull five cars.

Proposed potential of about 600 volts, direct supply, unspecified number of stations, and did not suggest alternating currents, boosters or storage batteries.

May, 1895.—Metropolitan West Side Elevated Railroad equipped under the supervision of Mr. W. E. Baker, and using General Electric Company's apparatus, opened on locomotive car plan, using two motors on locomotive car. This was the first commercial electric elevated road put into operation in the United States.

June 27, 1895.—First of three ninety-five-ton locomotives put in operation in Baltimore, by General Electric Company for pulling freight and passenger trains through B. & O. tunnel.

September 20, 1896. Lake Street Elevated Railroad, which had been operated since October, 1893, with steam, began electrical operation, plans similar to those on the Metropolitan.

February 1, 1896.—(Daily paper.) Electric Storage Battery Company of Philadelphia, described and proposed a storage battery locomotive to pull trains, storage batteries to be used in combination with current from third rail.

February 8, 1896.—(Daily paper.) Sprague, in reply to strictures on the capacity of electric motors in a daily paper, offered, under $50,000 forfeiture, to equip a train which could be pulled by a locomotive car, and also by motors under each car simultaneously controlled, and to make a speed of forty miles an hour on express service.

April 17, 1896.—In interview in daily paper, Westinghouse, on behalf of the Westinghouse Electro-Magnetic Company, with what was called the Westinghouse-Wheelless System, proposed for all elevated and suburban roads the use of a contact pin system and the continuous current. At the same time it was stated that in ten days public demonstration was to be made to demonstrate the success of the Tesla alternating current motor for this purpose.

May, 1896.—Nantasket Beach Railroad put in by the N. Y. and N. H. R. R., under the supervision of Colonel Heft was opened—used General Electric apparatus and a locomotive car carrying passengers and pulling a trail car.

June 6, 1896.—Sprague proposed to Messrs. Gould, Sage and Galloway, special committee of Manhattan Elevated, to make demonstration equipment of multiple unit system.

July 16, 1896.—Exhibition by Westinghouse of contact pin system, made for benefit of Manhattan officials.

November 29, 1896.—Under the supervision of Mr. C. B. Martin, electric service was instituted on the Brooklyn Bridge R. R. Twenty motor cars, each equipped with four General Electric Company sixty-two and one-half H. P. motors, and hand control replaced the steam shifting engines, and were used in connection with the cable.

December 10, 1896.—The General Electric Company through its western office, proposed to the South Side Elevated Railroad an equipment of three and four-car trains, one of which should be a locomotive car having two motors, and six-car trains, one of which should be a locomotive car having four motors, guaranteeing that on the first combination thirty-five miles an hour could be made, and on the second, forty-five miles an hour between stations 2,000 feet apart. No central station system was described, either alternating or continuous, or any potential determined

December 10, 1896.—The Walker Manufacturing Company proposed to the South Side Elevated Railroad a system as follows :

Continuous current, station in middle, pressure 600 volts, three and four-car trains, one being a locomotive car having two 125 H. P. mo-

tors, and guaranteed to save seven minutes in the trip from Congress street to 63d street, a distance of about eight and one-half miles, that is, to make a schedule of nearly nineteen miles.

February 14, 1897.—Sprague again stated the possibilities of the multiple unit system to the Manhattan road, and again offered to make a demonstration equipment and to work up to eight-car lengths under every possible condition.

February 25, 1897.—Sargent & Lundy reported on general equipment for South Side road, giving summary of locomotive car proposals and their recommendation, one of which was to double up trains.

February 26, 1897.—Potter, engineer of the railway department of the General Electric Company, reported to the third vice-president at Schenectady his recommendations of a system for the Manhattan elevated, with details as follows:

Direct current, three-wire system, the cars on one track being in series with those on the other, 650 volts on each line, and 1,300 volts between power rails on the two tracks, the track rails to be used as the neutral wire; two power stations equipped with 2,300 kilowatt generators, direct current supply; five car trains to be pulled by a single motor car with four motors; possible boosters or storage batteries at South Ferry alone; no alternating current, no sub-stations proper, and no storage battery regulations at sub-stations.

About the same date, a system diametrically opposed in almost every essential was proposed and recommended to the general contractors for the Central London Railway by Mr. Parshall of the British Thomson-Houston Company, with the General Electric Company in consultation as sub-contractors.

This proposition opposed the three-wire system, and on about six miles of road recommended alternating current machines, four substations with rotary converters, no storage batteries, five-car trains pulled by electric locomotives pure and simple instead of locomotive cars. The locomotives are now being built and weigh forty-five tons each. The schedule is moderate, and acceleration and braking are aided by having the station at peak grades of from two to three per cent.

The Westinghouse company made proposals of something the same nature, and the Siemens-Halske proposed the three-wire system, one track being in series with the other.

March, 1897.—Sargent & Lundy issued general specifications calling for alternative proposals for:

Thirty-six locomotive cars each having four 125 H. P. motors.

Forty-five locomotive cars each having two 150 H. P. motors.

One hundred and twenty motor cars each having two 35 H. P. motors.

April, 1897.—General Electric Company through W. B. Potter, engineer of the railway department, proposed to the South Side Elevated Railroad four and five-car operation, one car being a locomotive with four motors.

April, 1897.—Westinghouse Electric & Manufacturing Company proposed to South Side elevated operation of five-car trains, one being a locomotive car equipped with four 125 H. P. motors, and guaranteed to make an eighteen-mile schedule.

April 7, 1897.—Sprague as consulting engineer condemned the locomotive car system for South Side road, and recommended the adoption of the multiple unit system.

April, 1897.—Messrs. Sargent & Lundy, after report by Sprague, abandoned the locomotive plans for the South Side elevated and fully endorsed the multiple unit system.

April, 1897.—Chief Engineer Wallace, of Illinois Central Railroad, stated that trains should be run in any length from one to a dozen cars and he hoped to be able to run them with a push-button.

April 17, 1897.—Sprague tendered to the South Side Elevated Railroad a proposal to equip 120 cars on multiple unit system.

May, 1897.—Chief Engineer George B. Cornell, of the Brooklyn Elevated road, stated that two essentials of his endorsement of any change from steam to electricity on that road were increase of schedule speed and a control which could enable him to run single cars or any desired aggregation of cars into trains.

1897.—Short, for Walker Manufacturing Co., and the Westinghouse Company also, proposed various locomotive car plans for Manhattan Elevated.

July 16, 1897.—Sprague made demonstration at Schenectady of two-car multiple unit train, and ten days later of six-car train.

November–December, 1897.—Sprague made working test of multiple unit train on Metropolitan elevated of Chicago of five-car multiple unit train.

Fall of 1897.—On the Brooklyn Elevated Railroad the General Electric Company's engineers recommended for a fifteen-mile schedule four and five-car trains, two of the cars being locomotive cars, each weighing about thirty-five tons and equipped with four motors, with through connections of the main circuits, so that either the four or five-car unit could be operated from either one of the locomotive cars from a hand control. No independent operation of other car was proposed. An alternating current central station with sub-stations, rotary converters and storage batteries were also recommended.

1897.—Short, for Walker Manufacturing Co., and the Westinghouse Co., also proposed various locomotive car plans for the Manhattan elevated

December 23, 1897.—Sprague Electric Company sent the Illinois Central Railroad Company on specifications of Mr. John Lundie, the consulting engineer, a bid for an equipment for the suburban service of the Illinois Central Railroad, to use direct current system, with storage battery equalizers, individually equipped cars, multiple unit system, and to make a schedule speed of twenty-four and one-half miles with stations averaging 2,900 feet apart.

December 23, 1897.—On same specifications General Electric Company made similar bids to the Illinois Central under agreement to get controllers for same from Sprague company in case their bid should be accepted.

January 12, 1898.—Mr. Sprague proposed to Mr. Gould to operate any combination of from one to ten cars under any conditions of rail on multiple unit system.

February 18, 1898.—Sprague tendered to the Brooklyn Elevated Railroad the multiple unit system. For temporary use, twenty-four equipments were consolidated on twelve cars to be used first as locomotive cars, and afterwards to be distributed.

The motor equipments were to be designed for seventeen mile schedule with existing station intervals.

Those on the South Side were designed for a fifteen-mile schedule, but make sixteen and one-half at times, with longer intervals.

February, 1898.—The General Electric engineers offered to supply on the first twelve cars actually equipped by the Brooklyn Elevated Railroad, motors with either hand or semi-automatic control, and proposed to supply four or five months later, when developed, a full multiple unit control.

April 20, 1898.—Sprague began operations on South Side road with multiple unit system.

June 18, 1898.—Sprague began operation on the Bridge end of the Brooklyn "L" road.

July 12, 1898.—Waterloo & City, London. Straight run one and one-half miles, no mid-station. Operates light four-car train units, the two end ones being motor cars with two motors, and the intermediates being dead cars.

July 27, 1898.—Multiple unit system in full operation on South Side road, and steam abandoned.

Equipment on South Side road afterwards increased to 180 cars, 150 of which are fully equipped, and thirty, for emergency service, partially equipped.

November 1, 1898.—Westinghouse company began to put twenty cars on the Kings County Elevated Railroad, each equipped with two sets of two motors with controllers actuated by air pistons and controlled by a secondary electric circuit. Four only out of the twenty cars are in use at present and for locomotive purposes.

1898.—General Electric Company proposed six-car trains and double locomotive cars for the Manhattan elevated, and three car trains with a single locomotive car for the Boston elevated.

And finally the engineers of the General Electric and Westinghouse companies are credited with the intention to operate experimental multiple unit trains.

Of course, there are a number of other proposals which have been made both for multiple unit and other systems, and for various roads of which, however, mention is unnecessary for the present.

AMERICAN INSTITUTE OF ELECTRICAL ENGINEERS.

SIXTEENTH GENERAL MEETING.

BOSTON, June 26, 27 and 28, 1899.

The opening session of the Sixteenth General Meeting was called to order in the Walker Building, Massachusetts Institute of Technology, on Monday, June 26, at 10.30 A. M., by President Kennelly.

THE PRESIDENT:—I have great pleasure in introducing to the INSTITUTE His Honor, Mayor Quincy, who has kindly come to open our proceedings in the most acceptable and delightful manner.

MAYOR QUINCY:—Mr. President and Gentlemen of the AMERICAN INSTITUTE OF ELECTRICAL ENGINEERS:—I have merely come here this morning to fulfil the pleasing and unusual duty of welcoming your association to Boston upon the occasion of its meeting here. Boston has been favored by being selected as the gathering place of a great many national organizations of this sort, and I know that our citizens generally appreciate the compliment thus paid us, and are anxious to do anything in their power to make the stay of such bodies in Boston pleasant, and to make Boston an agreeable place for such purposes.

The particular objects of your organization appeal to me as having the greatest interest for all who are concerned in the technical, industrial and financial progress of the country. I suppose that it would be impossible to find in industrial history an instance of such a rapid development and such large financial investment in a new line as has been afforded by the history of the development of electricity, particularly in this country, but also throughout the world, since the date of the formation of your INSTITUTE. That date seems to mark about the period when electrical development on various lines passed from its experimental or preliminary stage to the stage of an assured basis, to the stage of rapid growth and to the stage where it offered

a field for the very large investment of capital, and the progress that has taken place since 1884 in the introduction, perfection and greater utilization of the telephone, of the arc light and of the incandescent light, and of the electric street railway and of electric motors for various purposes of power, seems to me to afford a history of unprecedented development, and I think that in the future those who study such things will look back upon this period of the last fifteen years as constituting one of the most interesting periods in the development of a new force, in the knowledge of how to handle it, and to apply it in a large way to the service of man, which can be found in the records of the world.

It has always seemed to me that the discovery which now seems to us so simple and elementary, of the possibility of converting power into electrical energy and transmitting it to great distances was, next to the invention of the steam engine, probably the greatest discovery that has ever been made; and as we look around us to-day and see the enormous factor which the telephone has become in the business life of the community, and is coming to fill more and more in the social life of the community, and perhaps most striking of all, as we see the enormous development of the electric railway, I think we can realize that we have to some extent already passed through and are passing through nothing less than an industrial revolution, a development which is so changing past methods and appliances that it is really entitled to that designation.

So much for the past. While the great inventions in electricity apparently have been made, while it is impossible it seems to me to conceive of such fundamental elementary discoveries in the field of electricity as have given us the electric motor, the telephone, the electric light and the electric street railway, yet I think we have by no means come to the end of electrical development upon the scientific and inventive side any more than we have upon the commercial side. While such a great change as has marked the introduction of electricity is scarcely possible in the future, yet I believe that the investment of capital in electricity will probably be still larger in the next fifteen years than it has been in the last fifteen years—enormous as that has been; and while the great main inventions, so to speak, have been made, I believe there is a vast work still to be done in the perfecting of various descriptions of apparatus and appliances for handling this comparatively new force.

It therefore seems to me a most excellent thing that the men who are making a study of this great subject from a strictly scientific and technical standpoint are joined together, organized in this AMERICAN INSTITUTE OF ELECTRICAL ENGINEERS. The development of every line must be led by a comparatively small number of men who do the work of research, the work of scientific study and the work of development; and the electrical en-

gineers of this country, comparatively few in number as they are, although somewhat rapidly growing in numbers within recent years, as our institutions of technical education are turning out new men to enter the ranks, have an opportunity to contribute in a very large way to the industrial and commercial development of this country; for of all forces I suppose that electricity is the most subtle; it is the most impalpable, its laws have been the most difficult to ascertain, and the field for scientific research in electricity certainly is still a very large and very fruitful one, and I believe that we are still to attain results of the very greatest importance through the theoretical study, through the scientific experiment and through the practical experience of such men as make up this organization.

Therefore it seems to me there can be no more interesting occasion than that which brings together the men who are engaged scientifically throughout the country in the development and in the practical handling of this great force of electricity; and I am sure that your deliberations and your exchange of experiences and of ideas and of scientific knowledge cannot but benefit this great line of thought and of development, and cannot but have a useful result for the many and varied interests which are now depending upon the continued development of this great new force which has come into the industrial life of the world, and which has already wrought such a marvelous revolution in the habits and methods of mankind.

The President:—I am sure we have all listened with great interest to the address of His Honor, and I feel sure that I am only voicing the general sentiment when I express to him the satisfaction we have had in listening to our opening address from him; and this meeting in Boston, the Sixteenth Meeting of this Institute, will be memorable to ourselves not merely from its having taken place in so great and historic a city, but having been called together under the auspices of such an excellent address of welcome. I have only one regret, and that is that His Honor is not one of us. It seems to me from the way he has handled some of the subjects he must have been one of us, and it is only by some oversight that he is not. We are much beholden to him, and we feel that he is in a sense one of our own workers.

The Secretary read a letter from Harvard University, also one from the Boston Electric Light Company; also one from the New England Telephone and Telegraph Company (offering for the use of members of the Institute to all parts of Boston and the suburbs a telephone set up in Room 14 of the building); also one from the American Telephone and Telegraph Company, the long distance service (offering for the use of the members a long distance telephone after six o'clock in the evening, set up in the Hotel Brunswick, and available to all points reached by the long distance telephone); one from the General Electric Company, Schenectady, New York, one from the Boston Terminal Com-

pany, one from Professor Elihu Thomson, extending an invitation to his house on Wednesday evening; one from the Vice-President's office of the Boston Elevated Railway; one from the Mayor of Cambridge; a letter of regret from Mr. Dunn saying he had been obliged to change his plans on account of his health, which necessitated his going to Haines Falls in the Catskills; a letter from the New England Gas and Coke Company, inviting the members to visit its new works at Everett.

THE PRESIDENT:—There is one report to be laid before the INSTITUTE this morning, and that is the report of the Committee on Standardization. The Chairman of that committee is Prof. Crocker, and I am sorry that Professor Crocker is abroad and not here to-day to present it. But this committee was appointed nearly two years ago and its provisional report was laid before the INSTITUTE at the last General Meeting a year ago at Omaha. The report has been before the INSTITUTE therefore for a year, and criticisms have been invited and a number have been received, and it is in printed form before you this morning. The matter is now before the INSTITUTE for action.

MR. A. V. GARRATT:—Mr. President, I believe that this report representing as it does a vast amount of careful, conscientious and well digested labor on the part of our very able Committee, should be either rejected or accepted as a whole as it is here printed before us. I therefore move you the acceptance of the report as presented to us in printed form and that it be published in the TRANSACTIONS.

[Motion seconded and adopted.]

AMERICAN INSTITUTE OF ELECTRICAL ENGINEERS.

HAVEMEYER BUILDING, 26 CORTLANDT STREET, NEW YORK, N. Y. JUNE, 1899.

REPORT OF THE COMMITTEE ON STANDARDIZATION.

[Accepted by the INSTITUTE, June 26th, 1899.]

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To The Council of The AMERICAN INSTITUTE OF ELECTRICAL ENGINEERS.

Gentlemen :

Your committee on Standardization begs to submit the following report, covering such subjects as have been deemed of pressing and immediate importance, and which are of such a nature that general agreement may be expected upon them.

While it is the opinion of the committee that many other matters might advantageously have been considered, as, for example, standard methods of testing ; yet it has been deemed inexpedient to attempt to cover in a single report more than is here submitted.

Yours respectfully,

FRANCIS B. CROCKER, *Chairman.*
CARY T. HUTCHINSON,
A. E. KENNELLY.
J. W. LIEB, JR.
CHARLES P. STEINMETZ.
LEWIS B. STILLWELL.
ELIHU THOMSON.

GENERAL PLAN.

Efficiency.	Sections 1 to 24			
	(I)	Commutating Machines,	Sections	6 to 11
	(II)	Synchronous Machines,	"	10 to 11
	(III)	Synchronous Commutating Machines,	"	12 to 15
	(IV)	Rectifying Machines,	"	16 to 17
	(V)	Stationary Induction Apparatus,	"	18 to 19
	(VI)	Rotary Induction Apparatus,	"	20 to 23
	(VII)	Transmission Lines,	"	24

Rise of Temperature. Sections 25 to 31

Insulation. Sections 32 to 41

Regulation. Sections 42 to 61

Variation and Pulsation. Sections 62 to 65

Rating. Sections 66 to 73

Classification of Voltages and Frequencies. Sections 74 to 78

Overload Capacities. Sections 79 to 82

Appendices.
(I) Efficiency.
(II) Apparent Efficiency.
(III) Power Factor and Inductance Factor.
(IV) Notation.
(V) Table of Sparking Distances.

Electrical Apparatus will be treated under the following heads:—

I. **Commutating Machines,** which comprise a constant magnetic field, a closed-coil armature, and a multi-segmental commutator connected thereto.

Under this head may be classed the following: Direct-current generators; direct-current motors; direct-current boosters; motor-generators; dynamotors; converters and closed-coil arc machines

A booster is a machine inserted in series in a circuit to change its voltage, and may be driven either by an electric motor, or otherwise. In the former case it is a motor-booster.

A motor-generator is a transforming device consisting of two machines; a motor and a generator, mechanically connected together.

A dynamotor is a transforming device combining both motor and generator action in one magnetic field, with two armatures or with an armature having two separate windings.

For Converters, see III.

II **Synchronous Machines,** which comprise a constant magnetic field, and an armature receiving or delivering alternating currents in synchronism with the motion of the machine; *i. e.*, having a frequency equal to the product of the number of pairs of poles and the speed of the machine in revolutions per second.

III. **Synchronous Commutating Machines**:—These include: 1. Synchronous converters; *i. e.*, converters from alternating to direct, or from direct to alternating current, and 2. Double-current generators; *i. e.*, generators producing both direct and alternating currents.

A converter is a rotary device transforming electric energy from one form into another without passing it through the intermediary form of mechanical energy.

A converter may be either:

a. A direct current converter, converting from a direct current to a direct current or,

b. A synchronous converter, formerly called a rotary converter, converting from an alternating to a direct current, or vice versa.

Phase converters, are converters from an alternating-current system to an alternating-current system of the same frequency but different phase.

Frequency converters are converters from an alternating-current system of one frequency to an alternating-current system of another frequency, with or without changes of phase.

IV. **Rectifying Machines, or Pulsating-Current Generators,** which produce a unidirectional current of periodically varying strength.

V. **Stationary Induction Apparatus,** *i. e.*, stationary apparatus changing electric energy from one form into another, without passing it through an intermediary form of energy. These comprise

a. Transformers, or stationary induction apparatus in which the primary and secondary windings are electrically insulated from each other.

b. Auto-transformers, formerly called compensators; *i. e.*, stationary induction apparatus in which part of the primary winding is used as a secondary winding; or conversely.

c. Potential regulators, or stationary induction apparatus having a coil in shunt, and a coil in series with the circuit, so arranged that the ratio of transformation between them is variable at will.

These may be divided into :—

1. Compensator potential regulators, in which the number of turns of one of the coils is changed

2. Induction potential-regulators, in which the relative positions of primary and secondary coils is changed.

3. Magneto potential-regulators, in which the direction of the magnetic flux with respect to the coils is changed.

d. Reactive coils, or Reactance coils, formerly called choking coils; *i. e.*, stationary induction apparatus used to produce impedance or phase displacement.

VI. **Rotary Induction Apparatus**, which consist of primary and secondary windings rotating with respect to each other. They comprise

a. Induction motors.

b. Induction generators.

c. Frequency changers.

d. Rotary phase converters.

EFFICIENCY.

1. The "efficiency" of an apparatus is the ratio of its net power output to its gross power input.[1]

2. Electric power should be measured at the terminals of the apparatus.

3. In determining the efficiency of alternating-current apparatus, the electric power should be measured when the current is in phase with the E. M. F., unless otherwise specified, except when a definite phase difference is inherent in the apparatus, as in induction motors, etc.

4. Mechanical power in machines should be measured at the pulley, gearing, coupling, etc., thus excluding the loss of power in said pulley, gearing or coupling, but including the bearing friction and windage. The magnitude of bearing friction and windage may be considered as independent of the load. The loss of power in the belt and the increase of bearing friction due to belt tension, should be excluded. Where, however, a machine is mounted upon the shaft of a prime mover, in such a manner that it cannot be separated therefrom, the frictional losses in bearings and in windage, which ought, by definition, to be included in determining the efficiency, should be excluded, owing to the practical impossibility of determining them satisfactorily. The brush friction, however, should be included.

a. Where a machine has auxiliary apparatus, such as an exciter, the power lost in the auxiliary apparatus should not be charged to the machine but to the plant consisting of machine and auxiliary apparatus taken together. The plant efficiency in such cases should be distinguished from the machine efficiency.

5. The efficiency may be determined by measuring all the losses individually and adding their sum to the output to derive the input, or subtract-

1. An exception should be noted in the case of storage batteries or apparatus for storing energy, in which the efficiency, unless otherwise qualified, should be understood as the ratio of the energy output to the energy intake in a normal cycle.

ing their sum from the input to derive the output. All losses should be measured at, or reduced to, the temperature assumed in continuous operation, or in operation under conditions specified. (See Sections 25 to 31.)

In order to consider the application of the foregoing rules to various machines in general use, the latter may be conveniently divided into classes as follows:

I. Commutating Machines.

6. In commutating machines the losses are :—

a. Bearing friction and windage. (See Section 4.)

b Molecular magnetic friction, and eddy currents in iron and copper. These losses should be determined with the machine on open circuit, and at a voltage equal to the rated voltage $+Ir$ in a generator, and $-Ir$ in a motor, where I denotes the current strength, and r denotes the internal resistance of the machine. They should be measured at the correct speed and voltage, since they do not usually vary in proportion to the speed or to any definite power of the voltage.

c. Armature resistance losses, I^2r', where I is the current strength in the armature, and r' is the resistance between armature brushes, excluding the resistance of brushes and brush contacts.

d. Comutator brush friction.

e. Commutator brush-contact resistance. It is desirable to point out that with carbon brushes the losses (*d*) and (*e*) are usually considerable in low-voltage machines.

f. Field excitation. With separately excited fields, the loss of power in the resistance of the field coils alone should be considered. With shunt fields or series fields, however, the loss of power in the accompanying rheostat should also be included, the said rheostat being considered as an essential part of the machine, and not as separate auxiliary apparatus.

(*b*) and (*c*) are losses in the armature or "armature losses ;" (*d*) and (*e*) "commutator losses ;" (*f*) "field losses."

7. The difference between the total losses under load and the sum of the losses above specified, should be considered as "load losses," and are usually trivial in commutating machines of small field distortion. When the field distortion is large, as is shown by the necessity for shifting the brushes between no load and full load, or with variations of load, these load losses may be considerable, and should be taken into account. In this case the efficiency may be determined either by input and output measurements, or the load losses may be estimated by the method of Section II.

8. Boosters should be considered and treated like other direct-current machines in regard to losses.

9. In motor-generators, dynamotors or converters, the efficiency is the

$$\frac{\text{electric output}}{\text{electric input.}}$$

II. Synchronous Machines.—

10. In synchronous machines the output or input should be measured with the current in phase with the terminal E. M. F., except when otherwise expressly specified.

Owing to the uncertainty necessarily involved in the approximation of load losses, it is preferable, whenever possible, to determine the efficiency of synchronous machines by input and output tests.

11. The losses in synchronous machines are :

a. Bearing friction and windage ; see Sec. 4.

b. Molecular magnetic friction and eddy currents in iron, copper and other metallic parts. These losses should be determined at open circuit of the machine at the rated speed and at the rated voltage, $+Ir$ in a synchronous generator, $-Ir$ in a synchronous motor, where $I =$ current in armature, $r =$ armature resistance. It is undesirable to compute these losses from observations made at other speeds or voltages.

These losses may be determined either by driving the machine by a motor, or by running it as a synchronous motor, and adjusting its fields so as to get minimum current input and measuring the input by wattmeter. The

former is the preferable method, and in polyphase machines the latter method is liable to give erroneous results in consequence of unequal distribution of currents in the different circuits caused by inequalities of the impedance of connecting leads, etc.

c. Armature-resistance loss, which may be expressed by $p I^2 r$; where r = resistance of one armature circuit or branch, I = the current in such armature circuit or branch, and p = the number of armature circuits or branches.

d. Load losses as defined in section 7. While these losses cannot well be determined individually, they may be considerable and, therefore, their joint influence should be determined by observation. This can be done by operating the machine on short circuit and at full-load current, that is, by determining what may be called the "short-circuit core loss." With the low field intensity and great lag of current existing in this case, the load losses are usually greatly exaggerated.

One-third of the short-circuit core loss may, as an approximation, and in the absence of more accurate information, be assumed as the load loss.

e. Collector-ring friction and contact resistance. These are generally negligible, except in machines of extremely low voltage.

f. Field excitation. In separately-excited machines, the $I^2 r$ of the field coils proper should be used. In self-exciting machines, however, the loss in the field rheostat should be included. (See Section 6 *f*.)

III. Synchronous Commutating Machines.

12. In synchronous converters, the power on the alternating-current side is to be measured with the current in phase with the terminal E. M. F., unless otherwise specified.

13. In double-current generators, the efficiency of the machine should be determined as a direct-current generator in accordance with section 6., and as an alternating-current generator in accordance with section 11. The two values of efficiency may be different, and should be clearly distinguished.

14. In synchronous converters the losses should be determined when driving the machine by a motor. These losses are :—

a. Bearing friction and windage, see section 4.

b. Molecular magnetic friction and eddy currents in iron, copper and metallic parts. These losses should be determined at open circuit and at the rated terminal voltage, no allowance being made for the armature resistance, since the alternating and the direct currents flow in opposite directions.

c. Armature resistance. The loss in the armature is $q I^2 r$, where I = direct current in armature, r = armature resistance and q, a factor which is equal to 1.37 in single-phasers, 0.56 in three-phasers, 0.37 in quarter-phasers and 0.26 in six-phasers

d Load losses The load losses should be determined in the same manner as described in section 11 *d*., with reference to the direct-current side.

e and *f*. Losses in commutator and collector friction and brush-contact resistance. See sections 6 and 11.

g. Field excitation. In separately-excited fields, the $I^2 r$ loss in the field coils proper should be taken, while in shunt and series fields the rheostat loss should be included, except where fields and rheostats are intentionally modified to produce effects outside of the conversion of electric power, as for producing phase displacement for voltage control. In this case 25 per cent. of the $I^2 r$ loss in the field proper at non-inductive alternating circuit should be added as proper estimated allowance for normal rheostat losses. (See Section 6 *f*.)

15. Where two similar synchronous machines are available, their efficiency can be determined by operating one machine as a converter from direct to alternating, and the other as a converter from alternating to direct, connecting the alternating sides together, and measuring the difference between the direct-current input, and the direct-current output. This process may be modified by returning the output of the second machine

through two boosters into the first machine and measuring the losses. Another modification might be to supply the losses by an alternator between the two machines, using potential regulators.

IV. Rectifying Machines or Pulsating-Current Generators.—

16. These include : Open-coil arc machines, constant-current rectifiers, constant-potential rectifiers.

The losses in open-coil arc machines are essentially the same as in sections 6 to 9 (closed-coil commutating machines.) In alternating-current rectifiers, however, the output must be measured by wattmeter and not by voltmeter and ammeter, since owing to the pulsation of current and E. M. F., a considerable discrepancy may exist between watts and volt-amperes, amounting to as much as 10 or 15 per cent.

17. In constant-current rectifiers, transforming from constant-potential alternating to constant direct current by means of constant-current transformers and rectifying commutators, the losses in the transformers are to be included in the efficiency and have to be measured when operating the rectifier, since in this case the losses are generally greater than when feeding an alternating secondary circuit. In constant-current transformers the load losses are usually larger than in constant-potential transformers and thus should not be neglected.

The most satisfactory method of determining the efficiency in rectifiers is to measure electric input and electric output by wattmeter. The input is usually not non-inductive, owing to a considerable phase displacement and to wave distortion. For this reason the apparent efficiency should also be considered, since it is usually much lower than the true efficiency. The power consumed by the synchronous motor or other source driving the rectifier should be included in the electric input.

V. Stationary Induction Apparatus.—

18. Since the efficiency of induction apparatus depends upon the wave shape of E. M. F., it should be referred to a sine wave of E. M. F., except where expressly specified otherwise. The efficiency should be measured with non-inductive load, and at rated frequency, except where expressly specified otherwise. The losses are :

a. Molecular magnetic friction and eddy currents measured at open circuit and at rated voltage — Ir, where $I =$ rated current, $r =$ resistance of primary circuit.

b. Resistance losses, the sum of the $I^2 r$ of primary and of secondary in a transformer, or of the two sections of the coil in the compensator or auto-transformer, where $I =$ current in the coil or section of coil, $r =$ resistance.

c. Load losses ; *i. e.*, eddy currents in the iron and especially in the copper conductors, caused by the current. They should be measured by short-circuiting the secondary of the transformer and impressing upon the primary an E. M. F. sufficient to send full-load current through the transformer. The loss in the transformer under these conditions measured by wattmeter gives the load losses $+ I^2 r$ losses in both primary and secondary coils.

d. Losses due to the methods of cooling, as power consumed by the blower in air-blast transformers, and power consumed by the motor driving pumps in oil or water-cooled transformers. Where the same cooling apparatus supplies a number of transformers or is installed to supply future additions, allowance should be made therefor.

19. In potential regulators the efficiency should be taken at the maximum voltage for which the apparatus is designed, and with non-inductive load, unless otherwise specified.

VI. Rotary Induction Apparatus.

20. Owing to the existence of load losses and since the magnetic density in the induction motor under load changes in a complex manner, the efficiency should be determined by measuring the electric input by wattmeter and the mechanical output at the pulley, gear, coupling, etc.

21. The efficiency should be determined at the rated frequency and the input measured with sine waves of impressed E. M. F.

22. The efficiency may be calculated from the apparent input, the power factor, and the power output. The same applies to induction generators. Since phase displacement is inherent in induction machines, their apparent efficiency is also important.

23 In frequency changers; *i. e.*, apparatus transforming from a polyphase system to an alternating system of different frequency, with or without a change in the number of phases, and phase converters; *i. e.*, apparatus converting from an alternating system, usually single phase, to another alternating system, usually polyphase. of the same frequency, the efficiency should also be determined by measuring both output and input.

VII. Transmission Lines.

24. The efficiency of transmission lines should be measured with non-inductive load at the receiving end, with the rated receiving pressure and frequency, also with sinusoidal impressed E M. F.'s., except where expressly specified otherwise, and with the exclusion of transformers or other apparatus at the ends of the line.

RISE OF TEMPERATURE.

General Principles.—

25. Under regular service conditions, the temperature of electrical machinery should never be allowed to remain at a point at which permanent deterioration of its insulating material takes place.

26. The rise of temperature should be referred to the standard conditions of a room-temperature of 25° *C.*, a barometric pressure of 760 mm. and normal conditions of ventilation; that is, the apparatus under test should neither be exposed to draught, nor enclosed, except where expressly specified.

27. If the room temperature during the test differs from 25° *C.*, the observed rise of temperature should be corrected by 1/2 per cent for each degree *C.*[2] Thus, with a room temperature of 35° *C.*, the observed rise of temperature has to be decreased by 5 per cent, and with a room temperature of 15° *C.*, the observed rise of temperature has to be increased by 5 per cent. The thermometer indicating the room temperature should be screened from thermal radiation emitted by heated bodies, or from draughts of air. When it is impracticable to secure normal conditions of ventilation on account of an adjacent engine, or other sources of heat, the thermometer for measuring the air temperature should be placed so as fairly to indicate the temperature which the machine would have if it were idle, in order that the rise of temperature determined shall be that caused by the operation of the machine.

28. The temperature should be measured after a run of sufficient duration to reach practical constancy. This is usually from 6 to 18 hours, according to the size and construction of the apparatus. It is permissible, however, to shorten the time of the test by running a lesser time on an overload in current and voltage, then reducing the load to normal, and maintaining it thus until the temperature has become constant.

In apparatus intended for intermittent service, as railway motors, starting rheostats, etc., the rise of temperature should be measured after a shorter time, depending upon the nature of the service, and should be specified.

In apparatus which by the nature of their service may be exposed to overload, as railway converters, and in very high voltage circuits, a smaller rise of temperature should be specified than in apparatus not liable to overloads or in low-voltage apparatus. In apparatus built for conditions of limited space, as railway motors, a higher rise of temperature must be allowed.

2. This correction is also intended to compensate, as nearly as is at present practicable, for the error involved in the assumption of a constant temperature coefficient of resistivity; *i. e.* 0.4 per cent. per deg. C. taken with varying initial temperatures.

29. In electrical conductors, the rise of temperature should be determined by their increase of resistance. For this purpose the resistance may be measured either by galvanometer test, or by drop-of-potential method. A temperature coefficient of 0.4 per cent per degree C., may be assumed for copper.[3] Temperature elevations measured in this way are usually in excess of temperature elevations measured by thermometers.

30. It is recommended that the following maximum values of temperature elevation should not be exceeded:

Commutating machines, rectifying machines, and synchronous machines.

Field and armature. by resistance, 50° C.

Commutator and collector rings and brushes, by thermometer, 55° C.

Bearings and other parts of machine, by thermometer, 40° C.

Rotary induction apparatus:

Electric circuits, 50° C., by resistance.

Bearings and other parts of the machine 40° C., by thermometer.

In squirrel cage or short-circuited armatures, 55° C., by thermometer, may be allowed.

Transformers for continuous service—electric circuits by resistance 50° C., other parts by thermometer, 40° C., under conditions of normal ventilation.

Reactive coils, induction and magneto regulators—electric circuits by resistance 55°C., other parts by thermometer 45°C.

Where a thermometer, applied to a coil or winding, indicates a higher temperature elevation than that shown by resistance measurement, the thermometer indication should be accepted. In using the thermometer, care should be taken so to protect its bulb as to prevent radiation from it, and, at the same time, not to interfere seriously with the normal radiation from the part to which it is applied.

31. In the case of apparatus intended for intermittent service, the temperature elevation which is attained at the end of the period corresponding to the term of full load, should not exceed 50° C by resistance in electric circuits. In the case of transformers intended for intermittent service, or not operating continuously at full load, but continuously in circuit, as in the ordinary case of lighting transformers, the temperature elevation above the surrounding air-temperature should not exceed 50° C by resistance in electric circuits and 40° C by thermometer in other parts, after the period corresponding to the term of full load. In this instance, the test load should not be applied until the transformer has been in circuit for a sufficient time to attain the temperature elevation due to core loss. With transformers for commercial lighting, the duration of the full-load test may be taken as three hours, unless otherwise specified. In the case of railway, crane, and elevator motors, the conditions of service are necessarily so varied that no specific period corresponding to the full-load term can be stated.

INSULATION.

32. The ohmic resistance of the insulation is of secondary importance only, as compared with the dielectric strength, or resistance to rupture by high voltage.

Since the ohmic resistance of the insulation can be very greatly increased by baking, but the dielectric strength is liable to be weakened thereby, it is preferable to specify a high dielectric strength rather than a high insulation resistance. The high voltage test for dielectric strength should always be applied.

Insulation Resistance.

33. Insulation resistance tests should, if possible, be made at the pressure for which the apparatus is designed.

The insulation resistance of the complete apparatus must be such that the rated voltage of the apparatus will not send more than $\frac{1}{1{,}000{,}000}$ of the full load current, at the rated terminal voltage, through the insulation. Where the value found in this way exceeds 1 megohm, 1 megohm is sufficient.

3. By the formula $R_T = R_t\ (1+0.004\ \theta)$. Where R_t is the resistance at room temperature, R_T the resistance when heated, and θ the temperature elevation $(T-t)$ in degrees centigrade.

Dielectric Strength.

34. The dielectric strength or resistance to rupture should be determined by a continued application of an alternating E. M. F. for one minute The source of alternating E. M. F. should be a transformer of such size that the charging current of the apparatus as a condenser does not exceed 25% of the rated capacity of the transformer.

35. The high voltage tests should not be applied when the insulation is low, owing to dirt or moisture, and should be applied before the machine is put into commercial service.

36. It should be pointed out that tests at high-voltages considerably in excess of the normal voltages are admissible on new machines, to determine whether they fulfill their specifications, but should not be made subsequently at a voltage much exceeding the normal, as the actual insulation of the machine may be weakened by such tests

37. The test for dielectric strength should be made with the completely assembled apparatus and not with its individual parts, and the voltage should be applied as follows :—

1st. Between electric circuits and surrounding conducting material, and,

2nd. Between adjacent electric circuits, where such exist, as in transformers.

The tests should be made with a sine wave of E. M. F., or where this is not available, at a voltage giving the same striking distance between needle points in air, as a sine wave of the specified E. M. F., except where expressly specified otherwise. As needles, new sewing needles should be used. It is recommended to shunt the apparatus during the test by a spark gap of needle points set for a voltage exceeding the required voltage by 10%.

A table of approximate sparking distances is given in Appendix V.

38. The following voltages are recommended for apparatus not including transmission lines or switchboards :

Rated Terminal Voltage.	Capacity.	Testing Voltage.
Not exceeding 400 volts	Under 10 K. W.	1000 volts.
" " "	10 K.W. and over	1500 "
400 and over, but less than 800 volts.	Under 10 K. W.	1500 "
" " " "	10 K. W. and over	2000 "
800 " " 1200 "	Any	3500 "
1200 " " 2500 "	Any	50 0 "
2500 "	Any	Double the normal rated voltages.
Synchronous motor fields and fields of converters started from the alternating current side		5000 volts.

Alternator field circuits should be tested under a breakdown test voltage corresponding to the rated voltage of the exciter, and referred to an output equal to the output of the alternator; *i. e.*, the exciter should be rated for this test as having an output equal to that of the machine it excites.

Condensers should be tested at twice their rated voltage and at their rated frequency.

The values in the table above, are effective values, or square roots of mean square, reduced to a sine wave of E. M. F.

39. In testing insulation between different electric circuits as between primary and secondary of transformers, the testing voltage must be chosen corresponding to the high-voltage circuit.

40. In transformers of from 10,coo volts to 20,000 volts, it should be considered as sufficient to operate the transformer at twice its rated voltage, by connecting first the one, and then the other terminal of the high-voltage winding to the core and to the low-voltage winding. The test of dielectric resistance between the low voltage winding and the core should be in accordance with the recommendation in Section 38, for similar voltages and capacities.

41. When machines or apparatus are to be operated in series, so as to employ the sum of their separate E. M. F's, the voltage should be referred to this sum, except where the frames of the machines are separately insulated both from gronnd and from each other.

REGULATION.

42 The term regulation should have the same meaning as the term "inherent regulation," at present frequently used.

43 The regulation of an apparatus intended for the generation of constant potential, constant current, constant speed, etc., is to be measured by the maximum variation of potential, current, speed, etc , occurring within the range from full load to no load, under such constant conditions of operation as give the required full-load values, the condition of full load being considered in all cases as the normal condition of operation.

44 The regulation of an apparatus intended for the generation of a potential, current, speed etc., varying in a definite manner between full load and no load, is to be measured by the maximum variation of potential current, speed, etc., from the satisfied condition, under such constant constant conditions of operation as give the required full-load values.

If the manner in which the variation in potential, current, speed, etc., between full load and no load is not specified, it should be assumed to be a simple linear relation ; *i. e.* undergoing uniform variation between full load and no load.

The regulation of an apparatus may, therefore, differ according to its qualification for use. Thus the regulation of a compound-wound generator specified as a constant-potential generator will be different from that it possesses when specified as an over-compounded generator.

45. The regulation is given in percentage of the full-load value of potential, current, speed, etc., and the apparatus should be steadily operated during the test under the same conditions as at full load.

46. The regulation of generators is to be determined at constant speed ; of alternating apparatus at constant impressed frequency.

47. The regulation of a generator-unit, consisting of a generator united with a prime-mover, should be determined at constant conditions of the prime mover ; *i. e.* constant steam pressure, head, etc. It would include the inherent speed variations of the prime mover. For this reason the regulation of a generator-unit is to be distinguished from the regulation of either the prime-mover, or of the generator contained in it, when taken separately.

48. In apparatus generating, transforming or transmitting alternating currents, regulation should be understood to refer to non-inductive load, that is to a load in which the current is in phase with the E. M. F. at the output side of the apparatus, except where expressly specified otherwise.

49. In alternating apparatus receiving electric power, regulation should refer to a sine wave of E. M. F., except where expressly specified otherwise.

50. In commutating machines, rectifying machines and synchronous machines, as direct-current generators and motors, alternating current and polyphase generators, the regulation is to be determined under the following conditions :

a. At constant excitation in separately excited fields

b. With constant resistance in shunt field circuits and

c. With constant resistance shunting series fields ; *i. e.*, the field adjustment should remain constant, and should be so chosen as to give the required full-load voltage at full-load current.

51. In constant-potential machines, the regulation is the ratio of the maximum difference of terminal voltage from the rated full-load value (occurring within the range from full load to open circuit) to the full-load terminal voltage.

52. In constant-current machines, the regulation is the ratio of the maximum difference of current from the rated full-load value (occurring within the range from full load to short circuit), to the full-load current.

53. In constant-power machines, the regulation is the ratio of maximum difference of power from the rated full load value (occurring within the range of operation specified) to the rated power.

54. In over-compounded machines, the regulation is the ratio of the maximum difference in voltage from a straight line connecting the no-load

and full-load values of terminal voltage as function of the current, to the full-load terminal voltage.

55. In constant-speed continuous-current motors, the regulation is the ratio of the maximum variation of speed from its full-load value (occurring within the range from full-load to no-load) to the full-load speed.

56. In transformers, the regulation is the ratio of the rise of secondary terminal voltage from full-load to no-load, (at constant primary impressed terminal voltage) to the secondary terminal voltage.

57. In induction motors, the regulation is the ratio of the rise of speed from full-load to no-load, (at constant impressed voltage), to the full-load speed. The regulation of an induction motor is, therefore, not identical with the slip of the motor, which is the ratio of the drop in speed from synchronism, to the synchronous speed.

58. In converters, dynamotors, motor-generators, and frequency changers, the regulation is the ratio of the maximum difference of terminal voltage at the output side from the rated full-load voltage, (at constant impressed voltage and at constant frequency), to the full-load voltage on the output side.

59. In transmission lines, feeders, etc., the regulation is the ratio of maximum voltage difference at the receiving end, between no-load and full non-inductive load, to the full-load voltage at the receiving end, with constant voltage impressed upon the sending end.

60. In steam engines, the regulation is the ratio of the maximum variation of speed in passing from full-load to no load (at constant steam pressure at the throttle), to the full-load speed.

61. In a turbine or other water-motor, the regulation is the ratio of the maximum variation of speed from full-load to no-load (at constant head of water; *i. e.*, at constant difference of level between tail race and head race), to the full-load speed.

Variation and Pulsation.—

62. In prime movers which do not give an absolutely uniform rate of rotation or speed, as in steam engines, the "variation" is the maximum angular displacement in position of the revolving member expressed in degrees, from the position it would occupy with uniform rotation, and with one revolution as 360°; and the pulsation is the ratio of the maximum change of speed in an engine cycle to the average speed.

63. In alternators or alternating-current circuits in general, the variation is the maximum difference in phase of the generated wave of E. M. F. from a wave of absolutely constant frequency, expressed in degrees, and is due to the variation of the prime mover. The pulsation is the ratio of the maximum change of frequency during an engine cycle to the average frequency.

64. If n = number of poles, the variation of an alternator is $\frac{n}{2}$ times the variation of its prime mover if direct connected, and $\frac{n}{2}p$ times the variation of the prime mover if rigidly connected thereto in the velocity ratio p.

65. The pulsation of an alternating-current circuit is the same as the pulsation of the prime mover of its alternator.

RATING.

66. Both electrical and mechanical power should be expressed in kilowatts, except when otherwise specified. Alternating-current apparatus should be rated in kilowatts on the basis of non-inductive condition; *i. e.*, with the current in phase with the terminal voltage.

67. Thus the electric power generated by an alternating-current apparatus equals its rating only at non-inductive load, that is when the current is in phase with the terminal voltage.

68. Apparent power should be expressed in kilovolt-amperes as distinguished from real power in kilowatts.

69 If a power-factor other than 100% is specified, the rating should be expressed in kilovolt-amperes and power-factor, at full load.

70. The full-load current of an electric generator is that current which with the rated full-load terminal voltage gives the rated kilowatts, but in alternating-current apparatus only at non-inductive load.

71. Thus in machines in which the full load voltage differs from the no-load voltage, the full load current should refer to the former.

If P = rating of an electric generator and E = full-load terminal voltage, the full-load current is:

$I = \frac{P}{E}$ in a continuous-current machine or single phase-alternator.

$I = \frac{P}{E\sqrt{3}}$ in a three-phase alternator.

$I = \frac{P}{2E}$ in a quarter-phase alternator.

72. Constant-current machines such as series arc-light generators, should be rated in kilowatts based on terminal volts and amperes at full load.

73. The rating of a fuse or circuit breaker should be the current-strength at which it will open the circuit, and not the working-current strength.

Classification of Voltages and Frequencies.

74. In direct current, low-tension generators, the following average terminal voltages are in general use and are recommended:

125 volts. 250 volts. 550 volts.

75. In direct-current, and alternating-current, low-pressure circuits, the following average terminal voltages are in general use and are recommended:

110 volts, 220 volts.

In direct-current power circuits, for railway and other service, 500 volts may be considered as standard.

76. In alternating-current, high-pressure circuits at the receiving end, the following pressures are in general use, and are recommended:

1000 volts. 2000 volts. 3000 volts. 6000 volts.
10000 volts. 15000 volts. 20000 volts.

77. In alternating-current high-pressure generators, or generating systems the following terminal voltages are in general use and are recommended:

1150 volts 2300 volts 3450 volts

These pressures allow of a maximum drop in transmission of 15% of the pressure at the receiving end. If the drop required is greater than 15%, the generator should be considered as special.

78. In alternating-current circuits, the following approximate frequencies are recommended as desirable:

25 ~ or 30 ~ 40 ~ 60 ~ 120 ~[4]

These frequencies are already in extensive use and it is deemed advisable to adhere to them as closely as possible.

Overload Capacities.

79. All guarantees on heating, regulation, sparking, etc., should apply to the rated load, except where expressly specified otherwise, and in alternating-current apparatus to the current in phase with the terminal E. M. F., except where a phase displacement is inherent in the apparatus.

80. All apparatus should be able to carry a reasonable overload without self destruction by heating, sparking, mechanical weakness, etc. and with an increase of temperature elevation not exceeding 15° C, above those specified for full loads. See Secs. 25 to 31.

81. Overload guarantees should refer to normal conditions of operation regarding speed, frequency, voltage, etc., and to non-inductive conditions in alternating apparatus, except where a phase displacement is inherent in the apparatus.

82. The following overload capacities are recommended:

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4. The frequency of 120~ may be considered as covering the already existing commercial frequencies between 120~ and 140~, and the frequency of 60 ~ as covering the already existing commercial frequencies between 60 ~ and 70 ~.

1st. In direct-current generators and alternating-current generators; 25% for one-half hour.

2d. In direct-current motors and synchronous motors, 25% for one-half hour, 50% for one minute; except in railway motors and other apparatus intended for intermittent service.

3d. Induction motors. 25% for one-half hour, 50% for one minute.

4th. Synchronous converters. 50% for one half hour.

5th. Transformers. 25% for one half hour. Except in transformers connected to apparatus for which a different overload is guaranteed, in which case the same guarantees shall apply for the transformers as for the apparatus connected thereto.

6th, Exciters of alternators and other synchronous machines, 10% more overload than is required for the excitation of the synchronous machine at its guaranteed overload, and for the same period of time.

APPENDIX I.

EFFICIENCY.

Efficiency of Phase-Displacing Apparatus.

In apparatus producing phase displacement as, for example, synchronous compensators, exciters of induction generators, reactive coils, condensers, polarization cells, etc., the efficiency should be understood to be the ratio of the volt-ampere activity to the volt-ampere activity plus power loss.

The efficiency may be calculated by determining the losses individually, adding to them the volt-ampere activity, and then dividing the volt-ampere activity by the sum.

1st. In synchronous compensators and exciters of induction generators, the determination of losses is the same as in other synchronous machines under Sections 10 and 11.

2nd. In reactive coils the losses are molecular friction, eddy losses, and I^2r loss. They should be measured by wattmeter. The efficiency of reactive coils should be determined with a sine wave of impressed E. M. F., except where expressly specified otherwise.

3rd In condensers, the losses are due to dielectric hysteresis and leakage and should be determined by wattmeter with a sine wave of E. M. F.

4th. In polarization cells, the losses are those due to electric resistivity and a loss in the electrolyte of the nature of chemical hysteresis and are usually very considerable. They depend upon the frequency, voltage and temperature, and should be determined with a sine wave of impressed E. M. F., except where expressly specified otherwise.

APPENDIX II.

Apparent Efficiency.

In apparatus in which a phase displacement is inherent to their operation, apparent efficiency should be understood as the ratio of net power output to volt-ampere input.

Such apparatus comprise induction motors, reactive synchronous converters, synchronous converters controlling the voltage of an alternating current system, self-exciting synchronous motors, potential regulators, and open magnetic circuit transformers, etc.

Since the apparent efficiency of apparatus generating electric power depends upon the power factor of the load, the apparent efficiency, unless otherwise specified, should be referred to a load power-factor of unity.

APPENDIX III.

Power Factor and Inductance Factor.

The power factor in alternating circuits or apparatus may be defined as the ratio of the electric power, in watts, to volt-amperes.

The inductance factor is to be considered as the ratio of wattless volt-amperes to total volt-amperes.

Thus, if p = power factor, q = inductance factor, then

$$p^2 + q^2 = 1$$

The power factor is the $\dfrac{\text{(energy component of current or E. M. F.)}}{\text{(total current or E. M. F.)}}$

and the inductance factor is the

$$\frac{\text{(wattless component of current or E. M. F.)}}{\text{(total current or E. M. F.)}} = \frac{\text{true power}}{\text{volt-amperes.}}$$

Since the power-factor of apparatus supplying electric power depends upon the power-factor of the load, the power-factor of the load should be considered as unity, unless otherwise specified.

APPENDIX IV.

The following notation is recommended :—

E, e, voltage, E. M. F., potential difference
I, i, current
P, power
Φ, magnetic flux
$\mathfrak{B}$, magnetic density
R, r, resistance
X x, reactance
Z, z, impedance
L, l, inductance
C, c, capacity.
Vector quantities when used should be denoted by capital italics.

APPENDIX V.

Table of Sparking Distances in Air between Opposed Sharp Needle-Points, for Various Effective Sinusoidal Voltages, in inches and in centimetres.

Kilovolts Sq. Root of Mean Square.	Distance. Inches	Cms.	Kilovolts Sq. Root of Mean Square.	Distance. Inches	Cms.
5	0.225	0.57	60	4.65	11.8
10	0.47	1.19	70	5.85	14.9
15	0.725	1.84	80	7.1	18.0
20	1.0	2.54	90	8.35	21.2
25	1.3	3.3	100	9.6	24.4
30	1.625	4.1	110	10.75	27.3
35	2.0	5.1	120	11.85	30.1
40	2.45	6.2	130	12.95	32.9
45	2.95	7.5	140	13.95	35.4
50	3.55	9.0	150	15.0	38.1

A paper presented at the Sixteenth General Meeting of the American Institute of Electrical Engineers, Boston, June 26th, 1899, President Kennelly in the Chair.

SYMBOLIC REPRESENTATION OF GENERAL ALTERNATING WAVES AND OF DOUBLE FREQUENCY VECTOR PRODUCTS.

BY CHARLES PROTEUS STEINMETZ.

PART I.

a. Graphically alternating currents and E. M. F.'s are usually represented by vectors. A vector is a quantity having length and direction. The length represents the intensity, the direction the phase of the alternating wave. The vectors generally issue from the center of co-ordinates.

In the topographical method, however, which is more convenient for complex networks, as interlinked polyphase circuits, the alternating wave is represented by the straight line between two points, these points representing the absolute values of potential (with regard to any reference point chosen as co-ordinate center) and their connection the difference of potential, in phase and intensity. Algebraically these vectors are represented by complex quantities. The impedance, admittance, etc., of the circuit is a complex quantity also, in symbolic denotation.

Thus current, E. M. F., impedance and admittance are related by multiplication and division of complex quantities similar as current, E. M. F., resistance and conductance are related by Ohm's law in direct current circuits.

In direct current circuits, power is the product of current into E. M. F. In alternating current circuits, if:

$$E = e^{1} + j\, e^{11}$$

$$I = i^{1} + j\, i^{11}$$

The product:

$$P_0 = E\,I = (e^1\,i^1 - e^{11}\,i^{11}) + j\,(e^{11}\,i^1 + e^1\,i^{11})$$

is not the power, that is multiplication and division which are correct in the inter-relation of current, E. M. F., impedance, do not give a correct result in the inter-relation of E. M. F., current, power. The reason is that $E\ I$ are vectors of the same frequency, and Z a constant numerical factor which thus does not change the frequency.

The power P, however, is of double frequency compared with E and I, and thus cannot be represented by a vector in the same diagram with E and I.

$P_0 = E\,I$ is a quantity of the same frequency with E and I and thus cannot represent the power.

b. Since the power is a quantity of double frequency of E and I, and thus the phase angle ω in E and I corresponds to a phase angle $2\,\omega$ in the power, it is of interest to investigate the product $E\,I$ formed by doubling the phase angle.

Algebraically it is:

$$P = E\,I = (e^1 + j\,e^{11})\,(i^1 + j\,i^{11}) =$$

$$(e^1\,i^1 + j^2\,e^{11}\,i^{11}) + (j\,e^{11}\,i^{11} + e^1\,j\,i^{11})$$

Since $j^2 = -1$, that is 180° rotation for E and I, for the double frequency vector, P, $j^2 = +1$, or 360° rotation, and

$$j \times 1 = j$$

$$1 \times j = -j$$

Hence, substituting these values, it is:

$$P = [E\,I] = (e^1\,i^1 + e^{11}\,i^{11}) + j\,(e^{11}\,i^1 - e^1\,i^{11})$$

The symbol $[E\,I]$ here denotes the transfer from the frequency of E and I to the double frequency of P.

The product: $P = [E\,I]$ consists of two components; the real component:

$$P^1 = [E\,I]^1 = (e^1\,i^1 + e^{11}\,i^{11})$$

and the imaginary component:

$$j\,P^j = j\,[E\,I]^j = j\,(e^{11}\,i^1 - e^1\,i^{11})$$

The component:

$$P^1 = [E\,I]^1 = (e^1\,i^1 + e^{11}\,i^{11})$$

is the power of the circuit, $= \text{E I} \cos (\text{E I})$

The component:

$$P^j = [E\,I]^j = (e^{11}\,i^1 - e^1\,i^{11})$$

is what may be called the "wattless power," or the powerless or quadrature volt-amperes of the circuit, $= \text{E I} \sin (\text{E I})$.

The real component will be distinguished by the index 1, the imaginary or wattless component by the index j.

By introducing this symbolism, the power of an alternating circuit can be represented in the same way as in the direct current circuit, as the symbolic product of current and E.M.F.

Just as the symbolic expression of current and E.M.F. as complex quantity does not only give the mere intensity, but also the phase:

$$E = e^1 + j\,e^{11}$$

$$\text{E} = \sqrt{e^{1^2} + e^{11^2}}$$

$$\tan \varphi = \frac{e^{11}}{e^1}$$

so the double frequency vector product $P = [E\,I]$ denotes more than the mere power, by giving with its two components $P^1 = [E\,I]^1$ and $P^j = [E\,I]^j$ the true energy volt-amperes, and the wattless volt-amperes.

If:

$$E = e^1 + j\,e^{11}$$

$$I = i^1 + j\,i^{11}$$

thus:

$$\text{E} = \sqrt{e^{1^2} + e^{11^2}}$$

$$\text{I} = \sqrt{i^{1^2} + i^{11^2}}$$

it is:

$$P^1 = [E\,I]^1 = (e^1\,i^1 + e^{11}\,i^{11})$$

$$P^j = [E\,I]^j = (e^{11}\,i^1 - e^1\,i^{11})$$

and:

$$P^{1^2} + P^{j^2} = e^{1^2}\,i^{1^2} + e^{11^2}\,i^{11^2} + e^{11^2}\,i^{1^2} + e^{1^2}\,i^{11^2}$$

$$= (e^{1^2} + e^{11^2})\,(i^{1^2} + i^{11^2})$$

$$= (\mathrm{E\,I})^2$$

$$= Q^2$$

where Q = total volt-amperes of circuit.

That is:

The true power P^1 and the wattless power P^j are the two rectangular components of the total apparent power Q of the circuit.

Herefrom it follows:

In symbolic representation as double frequency vector products, powers can be combined and resolved by the parallelogram of vectors just as currents and E.M.F.'s in graphical or symbolic representation.

Hereby the graphical methods of treatment of alternating current phenomena are extended to include double frequency quantities, as power, torque, etc.

It is:

$$\frac{P^1}{Q} = p = \cos\omega = \text{power factor.}$$

$$\frac{P^j}{Q} = q = \sin\omega = \text{inductance factor}$$

of the circuit, and the general expression of power is:

$$P = Q\,(p + j\,q)$$

$$= Q\,(\cos\omega + j\sin\omega)$$

(*c*.) The introduction of the double frequency vector product $P = [E\,I]$ brings us outside of the limits of algebra, however, and the commutative principle of algebra: $a \times b = b \times a$, does not apply any more, but it is:

$$[E\,I] \text{ unlike } [I\,E]$$

since:

$$[E\,I] = [E\,I]^1 + j\,[E\,I]^j$$

$$[I\,E] = [I\,E]^1 + j\,[I\,E]^j$$

$$= [E\,I]^1 - j\,[E\,I]^j$$

it is:

$$[E\,I]^1 = [I\,E]^1$$

$$[E\,I]^j = -\,[I\,E]^j$$

that is, the imaginary component reverses its sign by the interchange of factors.

The physical meaning hereof is: if the wattless power $[E\,I]^j$ is lagging with regard to E, it is leading with regard to I.

The wattless component of power is absent, or the total apparent power is true power, if:

$$[E\,I]^j = (e^{11}\,i^1 - e^1\,i^{11}) = 0.$$

that is:

$$\frac{e^{11}}{e^1} = \frac{i^{11}}{i^1}$$

or:

$$\tan(E) = \tan(I),$$

that is, E and I are in phase or in opposition.

The true power is absent, or the total apparent power wattless, if:

$$[E\,I]^1 = (e^1\,i^1 + e^{11}\,i^{11}) = 0$$

that is:

$$\frac{e^{11}}{e^1} = -\,\frac{i^1}{i^{11}}$$

or:

$$\tan E = -\cot I$$

that is, E and I are in quadrature.

The wattless power is lagging (with regard to E, or leading with regard to I) if:

$$[E\,I]^j > 0$$

and leading if:

$$[E\,I]^j < 0$$

The true power is negative, that is, power returns, if:

$$[E\,I]^1 < 0$$

It is:

$$[E, -I] = [-E\,I] = -[E\,I]$$

$$[-E, -I] = +[E\,I]$$

that is, when representing the power of a circuit or a part of a circuit, current and E.M.F. must be considered in their proper *relative* phases, but their phase relation with the remaining part of the circuit is immaterial.

(*d.*) If:

$$P_1 = [E_1\,I_1], \qquad P_2 = [E_2\,I_2] \ldots . P_n = [E_n\,I_n]$$

are the symbolic expressions of the power of the different parts of a circuit or network of circuits, the total power of the whole circuit or network of circuits is:

$$P = P_1 + P_2 + \ldots . + P_n$$

and it is:

$$P^1 = P_1^1 + P_2^1 + \ldots . + P_n^1$$

$$P^j = P_1^j + P_2^j + \ldots . + P_n^j$$

In other words the total power in symbolic expression (true as well as wattless) of a circuit or system is the sum of the powers of its individual components, in symbolic expression.

The first equation is obviously directly a result from the law of conservation of energy.

One result derived herefrom is for instance:

If in a generator supplying power to a system the current is out of phase with the E.M.F. so as to give the wattless power P^j, the current can be brought into phase with the generator E.M.F., or the load on the generator made non-inductive by inserting anywhere in the circuit an apparatus producing the wattless power $-P^j$, that is, compensation for wattless currents in a system takes place regardless of the location of the compensating device.

Obviously between the compensating device and the source of wattless currents to be compensated for, wattless currents will flow, and for this reason it may be advisable to bring the compensator as near as possible to the circuit to be compensated.

(*e.*) Like power, torque is a double frequency vector product also, of magnetism and M.M.F. or current, and thus can be treated in the same way.

In an induction motor, the torque is the product of the magnetic flux in one direction into the component of secondary induced current in phase with the magnetic flux in time, but in quadrature position therewith in space, times the number of turns of this current, or since the induced E.M.F. is in quadrature and proportional to the magnetic flux and the number of turns, the torque of the induction motor is the product of the induced E.M.F. into the component of secondary current in quadrature therewith in time and space, or the product of the induced current into the component of induced E.M.F. in quadrature therewith in time and space.

Thus, if :

$E = e^1 + j\, e^{11}$ = induced E.M.F. in one direction in space.

$I = i^1 + j\, i^{11}$ = secondary current in the quadrature direction in space,

the torque is :

$$T = [E\, I]^j = e^{11}\, i^1 - e^1\, i^{11}.$$

By this equation the torque is given in watts, the meaning being that $T = [E\, I]^j$ is the power which would be exerted by the torque at synchronous speed, or the torque in synchronous watts.

The torque proper is then :

$$\frac{T}{2\, \pi\, N\, p}$$

where :

p = number of pairs of poles of the motor.

Numerous instances of the the application of this are given in my previous paper on the single-phase induction motor.

As a further instance, we may consider the case of two polyphase induction motors in concatenation; that is, two equal in-

duction motors in which the secondary of the first motor is closed by the primary of the second motor, the motors being mechanically connected so as to run at the same speed.

In this case, let:

$N =$ frequency of main circuit,

$s =$ slip of the first motor from synchronism.

the frequency induced in the secondary of the first motor and thus impressed upon the primary of the second motor is, $s\,N$.

The speed of the first motor is $(1 - s)\,N$, thus the slip of the second motor, or the frequency induced in its secondary is

$$s\,N - (1 - s)\,N = (2\,s - 1)\,N.$$

Let:

$e =$ counter E.M.F. induced in the secondary of the second motor, reduced to full frequency.

$Z_0 = r_0 - j\,x_0 =$ primary self-inductive impedance.

$Z_1 = r_1 - j\,x_1 =$ secondary self-inductive impedance.

$Y = g + j\,b =$ primary exciting admittance of each motor all reduced to full frequency and to the primary by the ratio of turns.

It is then:

Second motor:

secondary induced E.M.F.:

$$e\,(2\,s - 1)$$

secondary current:

$$I_1 = \frac{e\,(2\,s - 1)}{r_1 - j\,(2\,s - 1)\,x_1} = e\,(a_1 + j\,a_2)$$

where:

$$a_1 = \frac{(2\,s - 1)\,r_1}{r_1^2 + (2\,s - 1)^2\,x_1^2} \qquad a_2 = \frac{(2\,s - 1)^2\,x_1}{r_1^2 + (2\,s - 1)^2\,x_1^2}.$$

primary exciting current:

$$I_0 = e\,(g + j\,b)$$

thus, total primary current:

$$I_2 = I_1 + I_0 = e\,(b_1 + j\,b_2)$$

where:

$$b_1 = a_1 + g \qquad\qquad b_2 = a_2 + b$$

primary induced E.M.F.:

$$s\,e$$

primary impedance voltage:

$$I_2\,(r_0 - j\,s\,x_0)$$

thus, primary impressed E.M.F.:

$$E_2 = s\,e + I_2\,(r_0 - j\,s\,x_0) = e\,(c_1 + j\,c_2)$$

where:

$$c_1 = s + r_0\,b_1 + s\,x_0\,b_2 \qquad\qquad c_2 = r_0\,b_2 - s\,x_0\,b_1$$

First motor:
secondary current:

$$I_2 = e\,(b_1 + j\,b_2)$$

secondary induced E.M.F.:

$$E_3 = E_2 + I_2\,(r_1 - j\,s\,x_1) = e\,(d_1 + j\,d_2)$$

where:

$$d_1 = c_1 + r_1\,b_1 + s\,x_1\,b_2 \qquad\qquad d_2 = c_2 + r_1\,b_2 - s\,x_1\,b_1$$

primary induced E.M.F.:

$$E_4 = \frac{E_3}{s} = e\,(f_1 + j\,f_2)$$

where:

$$f_1 = \frac{d_1}{s} \qquad\qquad f_2 = \frac{d_2}{s}\ *$$

primary exciting current:

$$I_4 = E_4\,(g + j\,b)$$

total primary current:

$$I = I_2 + I_4 = e\,(g_1 + j\,g_2)$$

---

* At $s = 0$ these terms f_1 and f_2 become indefinite, and thus at and very near synchronism have to be derived by substituting the complete expressions for f_1 and f_2.

where:

$$g_1 = b_1 + g f_1 - b f_2 \qquad g_2 = b_2 + g f_2 + b f_1$$

primary impedance voltage:

$$I (r_0 - j x_0)$$

thus, primary impressed E.M.F.:

$$E_0 = E_4 + I (r_0 - j x_0) = e (h_1 + j h_2)$$

where:

$$h_1 = f_1 + r_0 g_1 + x_0 g_2 \qquad h_2 = f_2 + r_0 g_2 - x_0 g_1$$

or, absolute:

$$e_0 = e \sqrt{h_1^2 + h_2^2}$$

and:

$$e = \frac{e_0}{\sqrt{h_1^2 + h_2^2}}$$

Substituting now this value of e in the preceding gives the values of the currents and E.M.F.'s in the different circuits of the motor series.

In the polyphase induction motor, the induced E.M.F. in quadrature in space to the induced E.M.F., E is:

$$j E.$$

Thus, in the second motor, the torque is:

$$T_2 = [j e I_1]^j = [e I_1]^1 = e^2 a_1$$

hence, its power output:

$$P_3 = (1 - s) T_2 = (1 - s) e^2 a_1$$

The power input is:

$$P_2 = [E_2 I_2] = [E_2 I_2]^1 + j [E_2 I_2]^j$$

$$= e^2 [(c_1 + j c_2) (b_1 + j b_2)]$$

hence, the efficiency:

$$\frac{P_3}{P_2^1} = \frac{(1 - s) e^2 a_1}{[E_2 I_2]^1} = \frac{(1 - s) a_1}{c_1 b_1 + c_2 b_2}$$

the power factor:

$$\frac{P_2^1}{Q} = \frac{[E_2\, I_2]^1}{E_2\, I_2} = \frac{c_1\, b_1 + c_2\, b_2}{\sqrt{(c_1^2 + c_2^2)\;(b_1^2 + b_2^2)}}$$

etc.

In the first motor:

the torque is:

$$T_1 = [E_4\, I_2]^1 = e^2\, [(f_1 + j\, f_2)\;(b_1 + j\, b_2)]^1$$
$$= e^2\,(f_1\, b_1 + f_2\, b_2)$$

the power output:

$$P_4 = T_1\,(1 - s)$$
$$= e^2\,(1 - s)\;(f_1\, b_1 + f_2\, b_2)$$

the power input:

$$P_1 = [E_0\, I\,] = e^2\;[(h_1 + j\; h_2)\,(g_1 + j\; g_2)]$$
$$= [E_0\, I\,]^1 + j\,[E_0\, I\,]^j$$

Thus, the efficiency:

$$\frac{P_4}{[E_0\, I\,]^1 - [E_2\;\, I_2]^1} = \frac{(1 - s)\,(f_1\, b_1 + f_2\, b_2)}{(h_1\, g_1 + h_2\, g_2) - (c_1\, b_1 + c_2\, b_2)}$$

the power factor of the whole system:

$$\frac{P_1}{E_0\, I} = \frac{h_1\, g_1 + b_2\, g_2}{\sqrt{(h_1^2 + h_2^2)\;(g_1^2 + g_2^2)}}$$

the power factor of the first motor:

$$\frac{P_1 - P_2}{E_0\, I - E_2\, I_2} = \frac{(h_1\, g_1 + h_2\, g_2) - (c_1\, b_1 + c_2\, b_2)}{\sqrt{(h_1^2 + h_2^2)\,(g_1^2 + g_2^2)} - \sqrt{c_1^2 + c_2^2)\,(b_1^2 + b_2^2)}}$$

the total efficiency of the system:

$$\frac{P_1 + P_3}{[E_0\;\, I\,]^1} = \frac{(1 - s)\;(f_1 + b_1 + f_2\, b_2 + a_1)}{h_2\, g_1 + h_2\, g_2}$$

etc.

As instance are given in Fig. 1. the curves of total torque, of

torque of the second motor, and of current, for the range of slip from $s = + 1.5$ to $s = - .7$ for a pair of induction motors in concatenation, of the constants:

$$Z_0 = Z_1 = .1 - .3 j$$

$$Y = .01 + .1 j.$$

FIG. 2 gives the curves of total torque and of current, from test of a motor of similar constants, for the range from

$$s = + 1 \text{ to } s = 0.$$

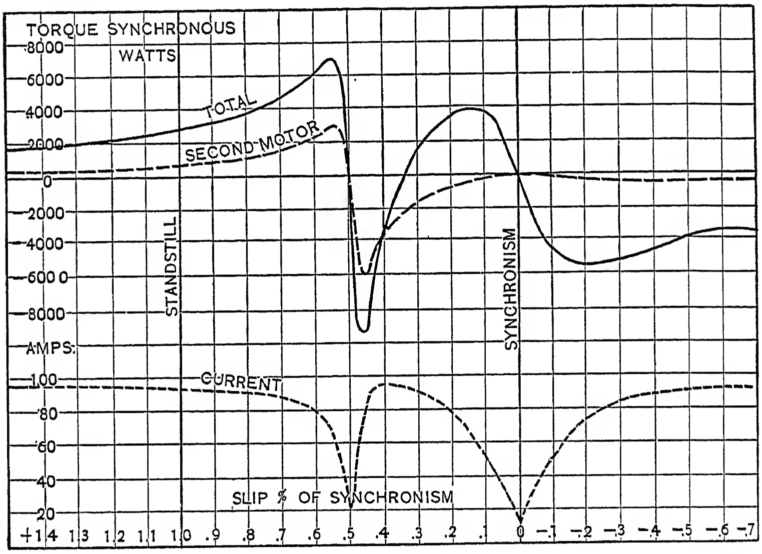


FIG. 1. Concatenation of Induction Motors. Speed Curves.

$Z = .1 - 3 j \quad Y = .01 + .1 j$

As seen, there are two ranges of positive torque for the whole system, one below half synchronism, and one from about $\frac{2}{3}$ to full synchronism, and two ranges of negative torque, or generator action of the motor, from half to two-third synchronism, and above full synchronism.

With higher resistance in the secondary of the second motor, the second range of positive torque of the system disappears more or less and the torque curves become as shown in Fig. 3.

Part II.

(*a.*) The vector representation:

$$A = a^1 + j\, a^{11} = a\,(\cos a + j \sin a)$$

of the alternating wave:

$$A = a_0 \cos(\varphi - a)$$

applies to the sine wave only.

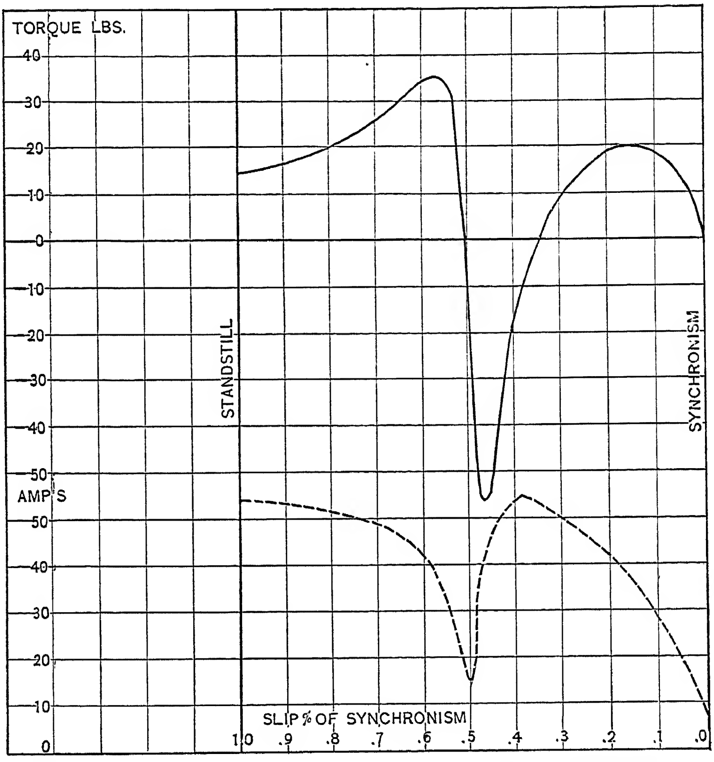


Fig. 2. Concatenation of Induction Motor. Speed Curves of two $I - 6 - 5 - 1200 - 110$.

The general alternating wave, however, contains an infinite series of terms, of odd frequencies:

$$A = A_1 \cos(\varphi - a_1) + A_3 \cos(3\,\varphi - a_3) + A_5 \cos(5\,\varphi - a_5) + .$$

thus can not directly be represented by one complex imaginary vector quantity.

The replacement of the general wave by its equivalent sine

wave, that is a sine wave of equal effective intensity and equal power, while sufficiently accurate in many cases, completely fails in other cases, especially in circuits containing capacity, or in circuits containing periodically (and in synchronism with the wave) varying resistance or reactance (as alternating arcs, reaction machines, synchronous induction motors, oversaturated magnetic circuits etc.)

Since however, the individual harmonics of the general alter-

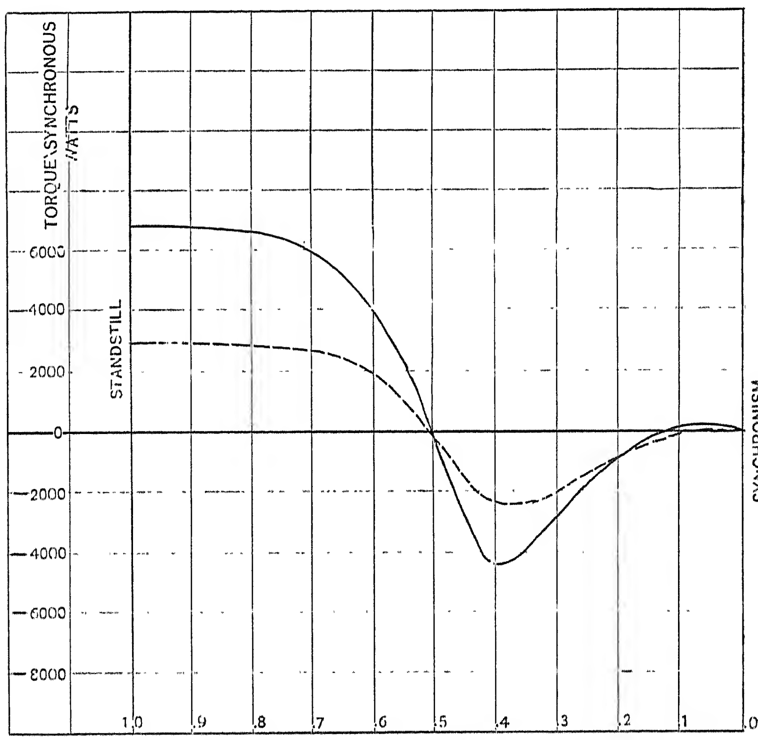


FIG. 3. Concatenation of Induction Motors Speed Curves.
$Z = .1 - .3j \quad Y = .01 + .1j$
Res. in Secondary of Second Motor.

nating wave are independent of each other, that is, all products of different harmonics vanish, each term can be represented by a complex symbol, and the equations of the general wave then are the resultants of those of the individual harmonics.

This can be represented symbolically, by combining in one formula symbolic representations of different frequencies, thus :

$$A = \sum_{1}^{\infty}{}_{2n-1} \, (a_n^{1} + j_n \, a_n^{11})$$

where:

$$j_n = \sqrt{-1}$$

and the index of the j_n merely denotes that the j's of different indices n, while algebraically identical, physically represent different frequencies, and thus can not be combined.

The general wave of E.M.F. is thus represented by:

$$E = \sum_{1}^{\infty}{}_{2n-1} \, (e_n^{1} + j_n \, e_n^{11})$$

the general wave of current by:

$$I = \sum_{1}^{\infty}{}_{2n-1} \, (i_n^{1} + j_n \, i_n^{11})$$

If:

$$Z_1 = r - j \, (x_m + x_0 + x_c)$$

is the impedance of the fundamental harmonic, where:

x_m is that part of the reactance which is proportional to the frequency (inductance, etc.)

x_0 is that part of the reactance which is independent of the frequency (mutual induction, synchronous motion, etc.)

x_c is that part of the reactance which is inverse proportional to the frequency (capacity, etc).

the impedance for the nth harmonic is:

$$Z = r - j_n \left(n \, x_m + x_0 + \frac{x_c}{n} \right)$$

This term can be considered as the general symbolic expression of the impedance of a circuit of general wave shape.

Ohm's law, in symbolic expression, assumes for the general alternating wave the form:

$I = \frac{E}{Z}$ or:

$$\sum_{1}^{\infty}{}_{2n-1} \, (i_n^{1} + j_n i_n^{11}) = \sum_{1}^{\infty}{}_{2n-1} \, \frac{e_n^{1} + j_n e_n^{11}}{r - j_n \left(n x_m + x_0 + \frac{x_c}{n} \right)}$$

$E = I\,Z$ or:

$$\sum_{1}^{\infty}{}_{2n-1}\,(e_n^{1} + j_n\,e_n^{11}) = \sum_{1}^{\infty}{}_{2n-1}\left[r - j_n\left(n x_m + x_0 + \frac{x_c}{n}\right)\right](i_n^{1} + j_n i_n^{11})$$

$Z = \dfrac{E}{I}$ or:

$$Z = r - j_n\left(n\,x_m + x_0 + \frac{x_c}{n}\right) = \frac{e_n + j_n\,e_n^{11}}{i_n^{1} + j_n\,i_n^{11}}$$

The symbols of multiplication and division of the terms E, I, Z, thus represent not algebraic operation, but multiplication and division of corresponding terms of E, I, Z, that is terms of the same index n, or, in algebraic multiplication and division of the series E, I, all compound terms, that is terms containing two different n, vanish.

(b.) The effective value of the general wave:

$$a = A_1 \cos(\varphi - a_1) + A_3 \cos(3\,\varphi - a_3) + A_5 \cos(5\,\varphi - a_5) + \ldots$$

is the square root of the sum of mean squares of individual harmonics:

$$A = \sqrt{\tfrac{1}{2}\,\{A_1^2 + A_3^2 + A_5^2 + \ldots\}}$$

since, as discussed above, the compound terms, of two different indices n, vanish, the absolute value of the general alternating wave:

$$A = \sum_{1}^{\infty}{}_{2n-1}\,\frac{a_n^{1} + j_n\,a_n^{11}}{b_n^{1} + j_n\,b_n^{11}}$$

is thus:

$$A = \sqrt{\sum_{1}^{\infty}{}_{2n-1}\,\frac{{a_n^{1}}^2 + {a_n^{11}}^2}{{b_n^{1}}^2 + {b_n^{11}}^2}}$$

which offers an easy means of reduction from symbolic to absolute values.

Thus, the absolute value of the E.M.F.

$$E = \sum_{1}^{\infty}{}_{2n-1} (e_n^1 + j_n e_n^{11})$$

is:

$$\text{E} = \sqrt{\sum_{1}^{\infty}{}_{2n-1} (e_n^{1^2} + e_n^{11^2})}$$

the absolute value of the current:

$$I = \sum_{1}^{\infty}{}_{2n-1} (i_n^1 + j_n i_n^{11})$$

is:

$$\text{I} = \sqrt{\sum_{1}^{\infty}{}_{2n-1} (i_n^{1^2} + i_n^{11^2})}$$

(*c*.) The double frequency power (torque, etc.) equation of the general alternating wave has the same symbolic expression as with the sine wave:

$$P = [E I]$$

$$= P^1 + j P^j$$

$$= [E I]^1 + j [E I]^j$$

$$= \sum_{1}^{\infty}{}_{2n-1} (e_n^1 i_n^1 + e_n^{11} i_n^{11}) + \sum_{1}^{\infty}{}_{2n-1} j_n (e_n^{11} i_n^1 - e_n i_n^{11})$$

where:

$$P^1 = [E I]^1 = \sum_{1}^{\infty}{}_{2n-1} (e_n^1 i_n^1 + e_n^{11} i_n^{11})$$

$$P^j = [E I]^j = \sum_{1}^{\infty}{}_{2n-1} \frac{j_n}{j} (e_n^{11} i_n^1 - e_n^1 i_n^{11})$$

The j_n enters under the summation sign of the "wattless power P^j, so that the wattless powers of the different harmonics can not be algebraically added.

Thus:

The total "true power" of a general alternating current circuit is the algebraic sum of the powers of the individual harmonics.

The total "wattless power" of a general alternating current circuit is not the algebraic, but the absolute sum of the wattless powers of the individual harmonics.

Thus, regarding the wattless power as a whole, in the general alternating circuit no distinction can be made between lead and lag, since some harmonics may be leading, others lagging.

The apparent power, or total volt-amperes, of the circuit is:

$$Q = \text{E I} = \sqrt{\sum_1^{\infty}{}_{2n-1} \left({e_n^1}^2 + {e_n^{11}}^2\right) \sum_1^{\infty}{}_{2n-1} \left({i_n^1}^2 + {i_n^{11}}^2\right)}$$

The power factor of the circuit is:

$$p = \frac{P^1}{Q} = \frac{\sum_1^{\infty}{}_{2n-1} \left(e_n^1 i_n^1 + e_n^{11} i_n^{11}\right)}{\sqrt{\sum_1^{\infty}{}_{2n-1} \left({e_n^1}^2 + {e_n^{11}}^2\right) \sum_1^{\infty}{}_{2n-1} \left({i_n^1}^2 + {i_n^{11}}^2\right)}}$$

The term "inductance factor" however, has no meaning any more, since the wattless powers of the different harmonics are not directly comparable.

The quantity:

$$q_0 = \sqrt{1 - p^2}$$

has no physical significance, and is not $\frac{\text{wattless power}}{\text{total apparent power}}$

The term:

$$\frac{P^1}{\text{E I}}$$

$$= \sum_1^{\infty}{}_{2n-1} \frac{e_n^{11} i_n^1 - e_n^1 i_n^{11}}{\text{E I}}$$

$$= \sum_1^{\infty}{}_{2n-1} q_n$$

where:

$$q_n = \frac{e_n^{11} i_n^1 - e_n^1 i_n^{11}}{\text{E I}}$$

consists of a series of inductance factors q_n of the individual harmonics.

As a rule,

$$p^2 + q^2 < 1$$

for the general alternating wave, that is q differs from

$$q_0 = \sqrt{1 - p^2}$$

The complex quantity :

$$U = \frac{P}{Q} = \frac{[E\,I]}{\mathrm{E\,I}} = \frac{[E\,I]^1 + j\,[E\,I]^j}{\mathrm{E\,I}}$$

$$= \frac{\sum_1^\infty{}_{2n-1}\ (e_n{}^1 i_n{}^1 + e_n{}^{11} i_n{}^{11}) + \sum_1^\infty{}_{2n-1}\ j_n\,(e_n{}^{11} i_n{}^1 - e_n{}^1 i_n{}^{11})}{\sqrt{\sum_1^\infty{}_{2n-1}\ (e_n{}^{1\,2} + e_n{}^{11\,2})\ \sum_1^\infty{}_{2n-1}\ (i_n{}^{1\,2} + i_n{}^{11\,2})}}$$

$$= p + \sum_1^\infty{}_{2n-1}\ j_n\ q_n$$

takes in the circuit of the general alternating wave the same position as power factor and inductance factor with the sine wave.

$$U = \frac{P}{Q} \text{ may be called the 'circuit factor.''}$$

It consists of a real term p, the power factor, and a series of imaginary terms $j_n\ q_n$, the inductance factors of the individual harmonics.

The absolute value of the circuit factor :

$$u = \sqrt{p^2 + (\sum_1^\infty{}_{2n-1}\ q_n)^2}$$

as a rule, is < 1.

Some applications of this symbolism will explain its mechanism and its usefulness more fully.

1*st Instance :* Let the E.M.F.:

$$E = \sum_1^5{}_{2n-1}\ (e_n{}^1 + j_n\ e_n{}^{11})$$

be impressed upon a circuit of the impedance:

$$Z = r - j_n \left(n\, x_m - \frac{x_c}{n} \right)$$

that is, containing resistance r, inductive reactance x_m and capacity reactance x_c in series.

Let:

$$e_1^{1} = 720 \qquad e_1^{11} = 540$$
$$e_3^{1} = 283 \qquad e_3^{11} = -283$$
$$e_5^{1} = -104 \qquad e_5^{11} = 138$$

or:

$$e_1 = 900 \qquad \tan \omega_1 = .75$$
$$e_3 = 400 \qquad \tan \omega_3 = -1$$
$$e_5 = 173 \qquad \tan \omega_5 = -1.33$$

It is thus in symbolic expression:

$$Z_1 = 10 + 80\, j_1 \qquad z_1 = 80.6$$
$$Z_3 = 10 \qquad z_3 = 10$$
$$Z_5 = 10 - 32\, j_5 \qquad z_5 = 33.5$$

and, E.M.F.:

$$E = (720 + 540\, j_1) + (283 - 283\, j_3) + (-104 + 138\, j_5)$$

or absolute:

$$E = 1000$$

and current:

$$I = \frac{E}{Z} = \frac{720 + 540\, j_1}{10 + 80\, j_1} + \frac{283 - 283\, j_3}{10} + \frac{-104 + 138\, j_5}{10 - 32\, j_5}$$

$$= (7.76 - 8.04\, j_1) + (28.3 - 28.3\, j_3) + (-4.86 - 1.73\, j_5)$$

or, absolute:

$$I = 41.85$$

of which is of fundamental frequency: $I_1 = 11.15$
" " " " triple " $I_3 = 40$
" " " " quintuple " $I_5 = 5.17$

The total apparent power of the circuit is:

$$Q = \text{E I} = 41{,}850$$

The true power of the circuit is:

$$P^1 = [E\,I]^1 = 1240 + 16{,}000 + 270$$
$$= 17{,}510$$

the wattless power:

$$j\,P^j = j\,[E\,I]^j = 10{,}000\,j_1 - 850\,j_5$$

thus, the total power:

$$P = 17{,}510 + 10{,}000\,j_1 - 850\,j_5$$

That is, the wattless power of the first harmonic is leading that of the third harmonic zero, and that of the fifth harmonic lagging.

$$17{,}510 = \text{I}^2\,r, \text{ as obvious.}$$

The circuit factor is:

$$U = \frac{P}{Q} = \frac{[E\,I]}{\text{E I}}$$
$$= .418 + .239\,j_1 - .0203\,j_5$$

or, absolute:

$$u = \sqrt{.418^2 + .2593^2}$$
$$= .492$$

The power factor is:

$$p = .418$$

The inductance factor of the first harmonic is: $q_1 = .239$, that of the third harmonic $q_3 = 0$, and of the fifth harmonic $q_5 = -.0203$.

Considering the waves as replaced by their equivalent sine waves, from the sine wave formula:

$$p^2 + q^2 = 1$$

the inductance factor would be:

$$q_0 = .914$$

and the phase angle:

$$\tan \omega = \frac{q_0}{p} = \frac{.914}{.418} = 2.8, \qquad \omega = 65.4^0$$

giving apparently a very great phase displacement, while in reality, of the 41.85 amperes total current, 40 amperes (the current of the third harmonic) are in phase with their E.M.F.

We thus have here a case of a circuit with complex harmonic waves which can not be represented by their equivalent sine waves. The relative magnitudes of the different harmonics in the wave of current and of E.M.F. differ essentially, and the circuit has simultaneously a very low power factor and a very low inductance factor, that is a low power factor exists without corresponding phase displacement, the circuit factor being less than one-half.

Such circuits for instance are those including alternating arcs, reaction machines, synchronous induction motors, reactances with over-saturated magnetic circuit, high potential lines in which the maximum difference of potential exceeds the voltage at which brush discharges begin, etc. Such circuits can not correctly, and in many cases not even approximately, be treated by the theory of the equivalent sine waves, but require the symbolism of the complex harmonic wave.

2nd Instance: A condenser of capacity $C_0 = 20$ M.F. is connected into the circuit of a 60-cycle alternator giving a wave of the form:

$$e = E\,(\cos \varphi - .10 \cos 3\,\varphi - .08 \cos 5\,\varphi + .06 \cos 7\,\varphi)$$

or, in symbolic expression:

$$E = e\,(1_1 - .10_3 - .08_5 + .06_7)$$

The synchronous impedance of the alternator is:

$$Z_0 = r_0 - j_n\, n\, x_0 = .3 - 5\, n\, j_n$$

What is the apparent capacity C of the condenser (as calculated from its terminal volts and amperes), when connected directly with the alternator terminals, and when connected thereto through various amounts of resistance and inductive reactance.

The capacity reactance of the condenser is:

$$x_c = \frac{10^6}{2\pi N C_0} = 132 \text{ ohms.}$$

or, in symbolic expression:

$$+ j_n \frac{x_c}{n} = \frac{132}{n} j_n$$

Let:

$Z_1 = r - j_n \, n \, x$ = impedance inserted in series with the condenser.

The total impedance of the circuit is then:

$$Z = Z_0 + Z_1 + j_n \frac{x_c}{n}$$

$$= (.3 + r) - j_n \left([5 + x] \, n - \frac{132}{n} \right)$$

The current in the circuit is:

$$I = \frac{E}{Z}$$

$$= e \left[\frac{1}{(.3+r) - j(x - 132)} - \frac{.1}{(.3+r) - j_3(3x - 29)} \right.$$

$$\left. - \frac{.08}{(.3+r) - j_5(5x - 1.4)} + \frac{.06}{(.3+r) - j_7(7x + 16.1)} \right]$$

and the E.M.F. at the condenser terminals:

$$E_1 = j_n \frac{x_c \, I}{n}$$

$$= e \left[\frac{132 j_1}{(.3+r) - j_1(x - 132)} - \frac{4.4 j_3}{(.3+r) - j_3(3x - 29)} \right.$$

$$\left. - \frac{2.11 j_5}{(.3+r) - j_5(5x - 1.4)} + \frac{1.13 j_7}{(.3+r) - j_7(7x + 16.1)} \right]$$

thus the apparent capacity reactance of the condensers:

$$x_1 = \frac{E_1}{I}$$

and the apparent capacity:

$$C = \frac{10^6}{2\,\pi\,N\,x_1}$$

(*a.*) $x = 0$: Resistance r in series with the condenser Reduced to absolute values, it is:

$$\frac{1}{x_1^{\,2}} = \frac{\frac{1}{(.3+r)^2+17424}+\frac{.01}{(.3+r)^2+841}+\frac{.0064}{(.3+r)^2+1.96}+\frac{.0036}{(.3+r)^2+259}}{\frac{17424}{(.3+r)^2+17424}+\frac{19.4}{(.3+r)^2+841}+\frac{4.45}{(.3+r)^2+1.96}+\frac{1.28}{(.3+r)^2+259}}$$

(*b.*) $r = 0$: Inductive reactance x in series with the condenser. Reduced to absolute values, it is:

$$\frac{1}{x_1^{\,2}} = \frac{\frac{1}{.09+(x-132)^2}+\frac{.01}{.09+(3x-29)^2}+\frac{.0064}{.09+(5x-1.4)^2}+\frac{.0036}{.09+(7x+16.1)^2}}{\frac{17424}{.09+(x-132)^2}+\frac{19.4}{.09+(3x-29)^2}+\frac{4.45}{.09+(5x-1.4)^2}+\frac{1.28}{.09+(7x+16.1)^2}}$$

From $\frac{1}{x_1^{\,2}}$ are derived the values of apparent capacity:

$$C = \frac{10^6}{2\,\pi\,N\,x_1}$$

and plotted in Fig. 4 for values of r and x respectively varying from 0 to 22 ohms.

As seen, with neither additional resistance nor reactance in series to the condenser, the apparent capacity with this generator wave is 84 M.F., or 4.2 times the true capacity, and gradually decreases with increasing series resistance, to $C = 27.5$ M.F. = 1.375 times the true capacity at $r = 13.2$ ohms or $\frac{1}{10}$ the true capacity reactance, with $r = 132$ ohms or with an additional resistance equal to the capacity reactance, $C = 20.5$ M. F. or only 2.5% in excess of the true capacity C_0, and at $r = \infty$, $C = 20.3$ M. F. or 1.5% in excess of the true capacity.

With reactance x but no additional resistance r in series, the apparent capacity C rises from 4.2 times the true capacity at $x = 0$, to a maximum of 5.03 times the true capacity or $C =$

100.6 M. F. at $x = .28$, the condition of resonance of the fifth harmonic, then decreases to a minimum of 27 M. F. or 35% in excess of the true capacity, rises again to 60.2 M. F. or 3.01 times the true capacity at $x = 9.67$, the condition of resonance with the third harmonic, and finally decreases, reaching 20 M. F. or the true capacity at $x = 132$ or an inductive reactance equal to the capacity reactance, then increases again to 20.2 M.F. at $x = \infty$.

This rise and fall of the apparent capacity is within certain limits independent of the magnitude of the higher harmonics of the generator wave of E. M. F., but merely depends upon their presence, and it thus follows that the true capacity of a condenser cannot even approximately be determined by measuring volts and amperes if there are any higher harmonics present in the

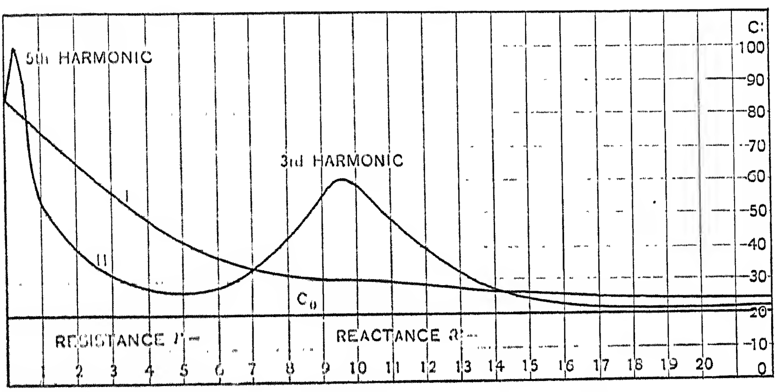


FIG. 4. Capacity $C_0 = 20$ *mf* in circuit of Generator $\mathfrak{E} = E\,(1 - .1 - .08 + .06)$ of impedance $Z_0 = .3 - 5\,j_n\,n$ with resistance r (*I*) or reactance x (*II*) in series.

generator wave, except by inserting a very large resistance or reactance in series to the condenser.

3rd Instance: An alternating current generator of the wave:

$$E_0 = 2000\,[1_1 + .12_3 - .23_5 - .13_7]$$

and of synchronous impedance:

$$Z_0 = .3 - 5\,n\,j_n$$

feeds over a line of impedance:

$$Z_1 = 2 - 4\,n\,j_n$$

a synchronous motor of the wave:

$$E_1 = 2250 \left[(\cos \omega + j_1 \sin \omega) + .24 (\cos 3 \omega + j_3 \sin 3 \omega)\right]$$

and of synchronous impedance:

$$Z_2 = .3 - 6 n j_n$$

The total impedance of the system is then:

$$Z = Z_0 + Z_1 + Z_2$$
$$= 2.6 - 15 n j_n$$

thus the current:

$$I = \frac{E_0 - E}{Z}$$

$$= \frac{2000 - 2250 \cos \omega - 2250 j_1 \sin \omega}{2.6 - 15 j_1} + \frac{240 - 540 \cos 3\omega - 540 j_3 \sin 3\omega}{2.6 - 45 j_3}$$

$$- \frac{460}{2.6 - 75 j_5} - \frac{260}{2.6 - 105 j_7}$$

$$= (a_1^1 + j_1 a_1^{11}) + (a_3^1 + j_3 a_3^{11}) + (a_5^1 + j_5 a_5^{11}) + (a_7^1 + j_7 a_7^{11})$$

where:

$a_1^1 = 22.5 - 25.2 \cos \omega + 146 \sin \omega$ $\quad a_1^{11} = 130 - 146 \cos \omega - 25.2 \sin \omega$

$a_3^1 = .306 - .69 \cos 3\omega + 11.9 \sin 3\omega$ $\quad a_3^{11} = 5.3 - 11.9 \cos 3\omega - .69 \sin 3\omega$

$a_5^1 = -.213$ $\quad a_5^{11} = -6.12$

$a_7^1 = -.061$ $\quad a_7^{11} = -2.48$

or, absolute:

1st. harmonic:

$$a_1 = \sqrt{{a_1^1}^2 + {a_1^{11}}^2}$$

3rd. harmonic:

$$a_3 = \sqrt{{a_3^1}^2 + {a_3^{11}}^2}$$

5th. harmonic:

$$a_5 = 6.12$$

7th. harmonic:

$$a_7 = 2.48$$

$$I = \sqrt{a_1^2 + a_3^2 + a_5^2 + a_7^2}$$

while the total current of higher harmonics is:

$$I_0 = \sqrt{a_3^2 + a_5^2 + a_7^2}$$

The true input of the synchronous motor is:

$$P_1 = [E_1 I]^1$$

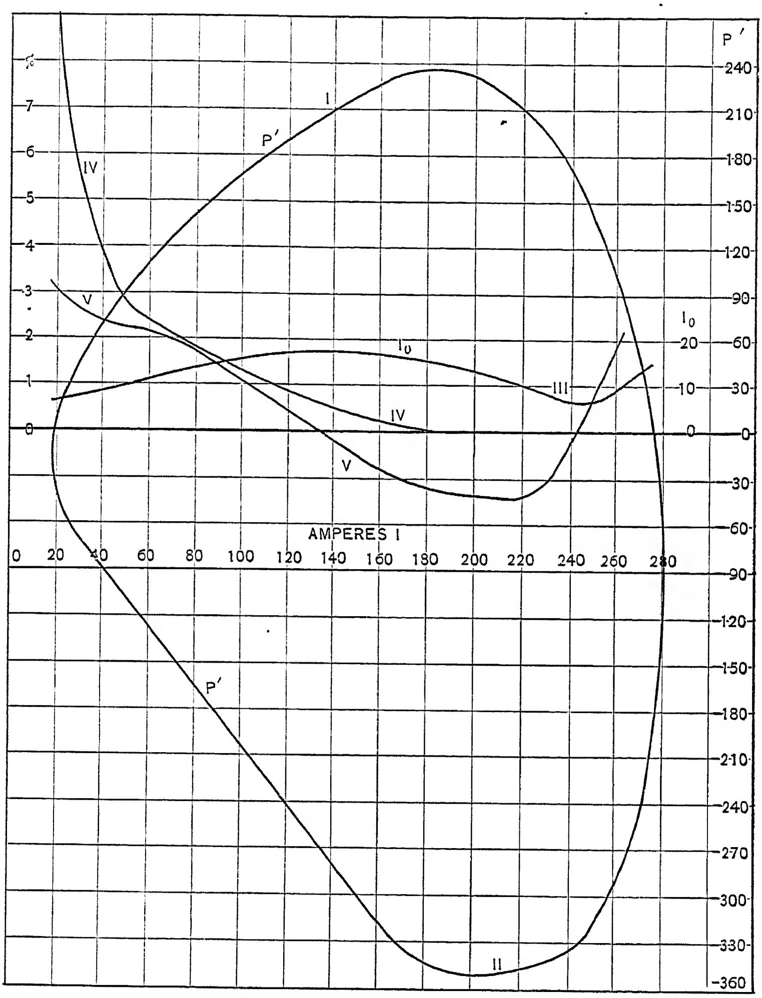


FIG. 5. Synchronous Motor.

$\mathfrak{E}_1 = (\cos. \omega + j_1 \sin. \omega) + .24 (\cos. 3\omega + j_3 \sin 3\omega.)$
Operated from Generator.
$\mathfrak{E}_0 = 2000 (1 + .12 - .23 - .13.)$
Over total impedance.
$Z_n = 2.6 - 15 j_n n.$

$$= (2250\, a_1^1 \cos \omega + 2250 a_1^{11} \sin \omega) + (540 a_1^1 \cos 3\omega + 540 a_3^{11} \sin 3\omega)$$

$$= P_1^1 + P_3^1$$

$$P_1^1 = 2250\, (a_1^1 \cos \omega + a_1^{11} \sin \omega)$$

is the power of the fundamental wave,

$$P_3^1 = 540\, (a_3^1 \cos 3\, \omega + a_3^{11} \sin 3\, \omega)$$

the power of the third harmonic.

The 5th and 7th harmonics do not give any power, since they are not contained in the synchronous motor wave.

Substituting now different numerical values for ω the phase angle between generator E.M.F. and synchronous motor counter E.M.F., corresponding values of the currents I I_0, and the powers P_1, P_1^1, P_3^1 are derived. These are plotted in Fig. 5 with the total current I as abcissae. To each value of the total current I correspond two values of the total power P^1, a positive value plotted as Curve I —synchronous motor—and a negative value plotted as Curve II — alternating current generator—. Curve III gives the total current of higher frequency I_0, Curve IV, the difference between the total current and the current of fundamental frequency, I — a_1, in percentage of the total current I, and *V* the power of the third harmonic, P_3^1, in percentage of the total power P^1.

Curves III, IV and V correspond to the positive or synchronous motor part of the power curve P^1.

As seen, the increase of current due to the higher harmonics is small, and entirely disappears at about 180 amperes.

The power of the third harmonic is positive, that is, adds to the work of the synchronous motor up to about 140 amperes or near the maximum output of the motor and then becomes negative.

It follows herefrom that higher harmonics in the E.M.F. waves of generators and synchronous motors do not represent a mere waste of current, but may contribute more or less to the output of the motor. Thus at 75 amperes total current, the percentage of increase of power due to the higher harmonic is equal to the increase of current, or in other words the higher harmonics of current do work with the same efficiency as the fundamental wave.

Discussion.

The President:—The paper is now before the Institute for discussion.

Dr. Louis Bell:—It strikes me that the most important proposition which Mr. Steinmetz has made is in calling attention to the facts regarding the imperfection of the ordinary sine wave computations in dealing with some phenomena which we encounter in those cases having combined capacity and inductance as in long lines. Again and again we find evidence in long line work of the existence of the higher harmonics. I think more and more in a practical way it is being forced on our attention that the variations from the sine waves make themselves felt in a very striking way. I firmly believe that by recognizing these variations in the treatment of the subject by complex quantities and bringing them into the summation so as to deal at least approximately with the conditions, thus bringing the analysis to bear on that one point, we shall be able to clear up a great many things now unexplained, and also very possibly to lick into shape the practice of dealing with currents containing harmonic factors so that we shall be able to understand more clearly what the conditions of minor resonance are and how to correct them. It is this phase of the matter which is most important. We are constantly running in practice against these variations from the sine wave.

Prof. Thomson:—I think Dr. Bell has hit the nail on the head in regard to this paper. He has voiced my opinion in regard to it. We are constantly striking things which appear to us anomalies. We measure the capacity of a condenser by an alternating current, we find that the result is all wrong, we can't get any consistent results. And such things we are meeting constantly, and Mr. Steinmetz himself is constantly meeting them I know on a large scale. This work of Mr. Steinmetz gives us a method of getting at an understanding and predicting results where formerly we had to experiment and take our chances.

The President:—The excellent paper before us marks an important step in the development of the vector analysis of alternating-current phenomena. Hitherto we have been compelled to limit the use of vectors to electromotive and magnetomotive forces, and their offspring currents and fluxes, and exclude activities. Mr. Steinmetz shows, however, that by adopting a separate vector plane for power we may also represent it by a vector having real and imaginary components corresponding to the real and wattless components. The advantages of this means of representing power are considerable, and we have only to take care not to confuse the plane of single frequency in which we draw our forces and currents, with the plane of double-frequency in which we draw our powers. The two planes must be kept

distinct in the mind and the algebraic laws they follow are also distinct.

Prof. W. E. Goldsborough:—I should like to say a word as coming from our universities to express how much we are indebted to Mr. Steinmetz for giving us a method, differing from the older methods we have used, which enables us to place before our students in a much more simple form many of the problems in electrical engineering. It is rather startling to the student at first to find that complex quantities admit of so direct and simple an application, but he is always charmed with the result. I doubt if Mr. Steinmetz fully appreciates the effect of his work in modifying the curricula of our American schools of electrical engineering; and in connection with this paper as in connection with the other valuable papers which he has given us I am glad to express the sentiment of our gratitude to him.

Prof. C. A. Adams, Jr.:—I wish to add one more word of gratitude for Mr. Steinmetz's valuable addition to his very valuable work along this line. I wish also to emphasize what Dr. Bell has said in regard to the practical importance of this subject of harmonics. Problems are continually arising in practice where they play a very active part, and this is not only true in long distance transmission lines, but also in the underground alternating current distribution in our large cities, particularly in Boston where the amount of such distribution is very considerable. Even in the case of the comparatively small fluctuations of the arc lighting current, there are strong indications of trouble from the same source.

Mr. T. J. Johnston:—I am not competent to criticize Mr. Steinmetz's paper, for like the famous Scotch joke, I have followed it with difficulty, but it seems to me that there is an error in the induction motor curves; taking Figs. 1, 2 and 3, the percentage of synchronism is given, for example, as one-tenth of one per cent., whereas it should be ten per cent.; in other words all of these figures are given one-one-hundredth of what they should be; I think Mr Steinmetz will corroborate that.

Some time ago Mr. Steinmetz explained to me in a general way the fact that the general alternating wave contained only odd harmonics, that is, as generated by dynamo and motor. I do not know whether that is so in relation to all alternating current apparatus, for example, the transformal and induction regulator; that is, I do not know whether there are even frequencies introduced into the wave by apparatus other than rotating armatures. I would like to have Mr. Steinmetz say whether that is true or not.

The President:—I would like to call attention to a point of terminology which may be important in the future and which ought to be cleared up. There is no doubt about the point in the paper, because the meaning is clearly defined. The term "torque" is used with a meaning which seems misleading, at

least to those who may not have the definition before them. It is stated to be the product of the E. M. F. into the quadrature component of secondary current. But this product is not a "torque" or "moment" but is a "power" or "activity," and it is defined as the power which the torque develops at synchronous speed. Now a torque cannot be both a torque and a power, because the one is a moment of a force about an axis and the other is a rate of working. Further on in the paper the "torque proper" is defined as this so-called synchronous torque divided by an angular velocity and by the number of poles. Surely it would be better to retain the term "torque" for this its usual meaning, and use some such term as "synchronous power" for the activity of the torque at synchronism.

MR. STEINMETZ:—Taking up the last question first, I appreciate that it is undesirable to denote by the same name two quantities of different dimensions. I was obliged, however, to introduce the definition of torque in synchronous watts as the only one suitable for general theoretical discussions, by its independence of individual conditions of the apparatus, as number of poles, frequency, etc.

In synchronous watts, torque has as definite a meaning as power in watts. To avoid the objection of the different dimension from torque as usually given in foot pounds, the value $T = e^2 a^1$, etc., may be divided by the frequency: $T_0 = \frac{e^2 a^1}{N}$ as indeed is implied by "synchronous" watts, or a new name may be invented for the quantity $T = e^2 a^1$ if anybody can suggest a suitable name.

The lettering on Figs. 1 and 2 is obviously a misprint which will be corrected, it should read "in fractions" and not "in per centages."

I would like to draw your attention to one curious and somewhat unexpected feature regarding the effect of higher harmonics of E. M. F. on the current input of the condenser.

The current input, and thus the apparent capacity of a condenser, when supplied by a wave of E. M. F., containing higher harmonics, is independent of the magnitude of the higher harmonics, provided that the resistance between generator and condenser is negligible, and depends upon the existence of th se harmonics only. Thus a quintuple harmonic of 25% of the fundamental will send neither more nor less current into a condenser at the same effective terminal voltage than a quintuple harmonic of 5% or less, at negligible resistance.

The only effect of the magnitude of higher harmonics is that the resistance which is negligible with a higher harmonic of 25% of the fundamental, may not be negligible with a higher harmonic of 5%, or in other words the lower the amplitude of the higher harmonics the lesser resistance is sufficient to suppress their effect on the condenser.

DR. BELL:—In this matter of torque, I must beg of Mr. Stein-

metz out of kindness to the profession not to invent a new name. We have now not a deficit but a plethora of new names and I think that a little clearer explanation would avoid what I should style a real calamity.

In respect to this matter of harmonics, one quickly realizes that when it comes to a matter of resonance, when there is true resonance, mechanical or of any other sort the original amplitude of the wave of energy does not make very much difference. It is the resistance to the propagation of the vibrations, whatever they may be, that determines the magnitude of resonance. So while it seems queer that a small fifth harmonic should raise the very deuce with the capacity of a condenser, we should remember that this condition expresses a general physical fact not at all confined to electrical problems.

PROF. H. J. RYAN:—May I say in answer to the gentleman who spoke of the even harmonics that the positive and negative magnetic flux must always have the same value. The E. M. F. values will therefore be alike and such values can therefore always be made up of components and the fundamental and the odd numbers of harmonics. The even numbers would represent a state of affairs in which the flux positive and negative would not be the same.

PROF. E. THOMSON:—There is just one point about the production of the even harmonics. We could provide for them without doubt by making a single conductor travel in front of magnetic poles of different width, say the north poles of a certain width and the south a greater or less width, and a single conductor would thus operate to produce the ordinary wave containing even harmonics.

MR. T. J. JOHNSTON:—We may take a vibrating string in music and split the vibration so that there will be two nodes, making the string vibrate in three parts, giving the third harmonic. Take another string and split that into two parts, giving rise to the second harmonic or octave, and the vibrations may be so mingled as to sound in the same wave both the second and third harmonics.

What I want to know is, is there anything analogous to that in the alternating circuit; by which, for example, by power from the outside a second harmonic may be introduced into that circuit, so that a second and third harmonic will flow in the same wave?

DR. SAMUEL SHELDON:—In instrumental music the duration of the different tones is represented by notes of different lengths as eighths, sixteenths and halves. There is also the tempo mark, and yet if we take a classic and place it in the hands of an inexperienced performer, although the directions on the printed page are followed perfectly, the resulting music is in no wise of the same character as if played by an artist. The difference between the performances of the two, the artist and the unskilled

performer, is largely a question of allowance in time. There is a subdivision of the different time intervals far below the limits which are represented on the printed music. These subdivisions are readily detected by the ear. In the question of alternating currents of course any problem could be easily solved were it not for phase differences. If we knew the instantaneous values of current, E. M. F., torque, etc., in a number of small successive time intervals we could solve without the use of any complex quantities. However, the difference between the ordinary person and the artist I think is well represented here to-day and I would like to add my word in appreciation of the artist who has presented this paper to us and who seems to perceive these little time intervals by self-consciousness.

PROF. GOLDSBOROUGH :—There is one matter which, so far, I believe, has not been touched upon, which is the use of complex quantities in connection with the design of electrical machinery. If we have harmonics in our circuits they are usually developed in the station generator. We know that whenever we use an iron-clad armature we get harmonics. If we follow the type of the smooth core armature it is possible to produce what is practically a pure sine wave. Now, as every introduction of inductance into the circuit, whether it be from transformers or induction motors or even from changes in the flux densities used in the iron of the alternator, modifies the character of the wave, it also modifies the amplitudes of the harmonics which are component parts of the wave, and there is presented a series of mutually related phenomena the treatment of which is very difficult. I think, therefore, that this paper which Mr. Steinmetz has brought out, showing us how we can apply complex quantities to the analyzation of problems involving harmonics, is a contribution of great value. In other words, by being able to analyze our generators properly, in the process of design, and thereby pre-determining the exact character of their regulation, we will be better able to adapt them to the needs for which they are built, and cut off in the development of the machines the undesirable qualities which cause trouble.

[COMMUNICATED AFTER ADJOURNMENT BY DUGALD C. JACKSON.]

Mr. Steinmetz makes a very interesting expansion, in this paper of his "symbolic" method of representing alternating waves, and the paper is undoubtedly a valuable contribution to the literature of the subject. It is pleasing to find Mr. Steinmetz bringing his analysis into more rational paths, as his apparent disregard in the past, of the imaginary or wattless component of the power vector must have led many students to question the generality and truth of his methods.

Even now, Mr. Steinmetz uses in Part I of the paper, what appears to me an unnatural treatment of the power vector, and I

therefore present for consideration a treatment abstracted from the notes of my lectures to advanced students of alternating currents. Polar coordinates are used in representing the vectors, instead of the rectangular coordinates used by Mr. Steinmetz. This is purely a matter of convenience, as the transformation from one set of coordinates to the other is readily effected. Letters in bold face type represent vectors and italics represent moduli or tensors.

The vector of electrical pressure is represented in polar coordinates by

$$\mathbf{E} = E(\cos\theta + i\sin\theta),$$

or, writing cis θ in the place of $(\cos\theta + i\sin\theta)$, to represent the direction coefficient or "turning factor" in the expression, gives

$$\mathbf{E} = E \operatorname{cis}\theta.$$

In the same way current is represented by

$$\mathbf{I} = I \operatorname{cis}(\theta - \varphi)$$

and impedance is

$$\mathbf{Z} = \frac{\mathbf{E}}{\mathbf{I}} = \frac{E}{I}\operatorname{cis}\varphi = Z\operatorname{cis}\varphi.$$

This quotient is drawn in accordance with the well-understood theorem that the ratio of two vectors has a tensor equal to the ratio of the tensors of dividend and divisor and an amplitude equal to the difference of the amplitudes of dividend and divisor.

Impedance is here shown to be a vector ratio or quaternion which has the characteristics of an operator. Its amplitude is wholly dependent upon **E** and **I**, it cannot be said to have a frequency of its own, and it clearly can have no effect upon the period of **E** and **I** which is determined by the period of θ, — a period which is in no manner dependent upon **Z**. On the other hand, Mr. Steinmetz is clearly in error when he asserts that, in vector equations, impedance, **Z**, "is a constant numerical factor" and for that reason does not affect the frequency when it operates on **I** to produce **E**.

The reciprocal of impedance, whatever its name may ultimately be, is of course,

$$\mathbf{Y} = \frac{I}{Z}\operatorname{cis}(-\varphi).$$

The power vector has the form

$$\mathbf{P} = P\operatorname{cis}\psi,$$

and it is equal to the product of the current and pressure vectors, or

$\mathbf{P} = \mathbf{I}\,\mathbf{E} = I\,E \operatorname{cis}(2\,\theta - \varphi) = (I\,E \cos\varphi - i\,I\,E \sin\varphi) \operatorname{cis} 2\,\theta.$ Cis ψ is therefore equal to cis $2\,\theta$, and it is clearly seen that **P** has twice the frequency of **I** and **E**. Moreover, the apparent energy P, is shown to be composed of two rectangular components. One of these ($I E \cos\varphi$) is real and represents the true average power in the period, and the other ($i\,I\,E \sin\varphi$) is imaginary, disappears when taken over any complete half period, and represents the *wattless energy* (if such a contradictory expression is allowable) that swashes back and forth in the circuit but always gives as much as it takes in any complete half period.

By drawing a curve through the points found by giving various values to θ from 0 to 360° in the expression P cis $2\,\theta$, we get the well known sinusoidal "power loops" which are of twice the frequency of the corresponding curves of pressure and current.

The true energy is zero when

$$\cos\varphi = 0,$$

that is, when $\varphi = 90°$, in which case **E** and **I** are in quadrature; and the *wattless energy* is zero when

$$\sin\varphi = 0,$$

that is, when $\varphi = 0°$ or $180°$, in which case **E** and **I** are either in phase or in opposition. Mr. Steinmetz's equations

$$\frac{e''}{e'} = -\frac{i'}{i''} \text{ and } \frac{e''}{e'} = \frac{i''}{i'}$$

are at once evident.

The algebraic sign of the angle φ indicates whether the *wattless energy* is the result of equivalent inductance or capacity, and its numerical value indicates whether the true power is delivered or absorbed by the circuit. The application of the commutative law to the vector formulas is not affected by doubling the amplitude in the equation.

All of the deductions which may be properly drawn from Mr. Steinmetz's discussion of the power vector may be more readily drawn from the forms given, which are not only in harmony with the ordinary analytic forms and appear to be more natural but contain indications of evident importance that do not appear in Mr. Steinmetz's forms.

The discussion may be simply and readily extended to torque and applied to the problems that Mr. Steinmetz introduces. As the important quantities in the solutions of the problems relate to the magnitude of torque, apparent energy, and true energy it is often convenient to transform into rectangular coordinates. This (using Mr. Steinmetz's notation) gives for apparent energy

$$P = P^1 + P^j = (e'\,i' + e''\,i'') \pm j\,(e''\,i' - e'\,i''),$$

where the plus or minus sign should be used between the two terms of the last member of the equation as φ is essentially positive or essentially negative.

The further transformations readily follow and it is unnecessary to extend the discussion for the purpose of showing them. Possibly it is needless to add that an analogous treatment is equally simple when applied to the matter of Part II of Mr. Steinmetz's paper.

THE CHAIRMAN:—We will pass to the next paper on the programme, which is "The Cost of Electricity in Some Typical Buildings in New York City," by Percival Robert Moses.

A paper presented at the Sixteenth General Meeting of the American Institute of Electrical Engineers, Boston, June 20th, 1899, President Kennelly in the Chair.

THE COST OF ELECTRICITY IN SOME TYPICAL BUILDINGS IN NEW YORK CITY.

BY PERCIVAL ROBERT MOSES.

For several years I have been questioned as to the cost of electricity in isolated plants and frequently the statement was volunteered that "of course the central station supply can offer much better terms." I have partially investigated the conditions existing in over a hundred buildings of various sizes and types, and as the subject is one of general interest to engineers and laymen. I have ventured to prepare a paper embodying the results I have found, and trust that the discussion thereof, will bring additional figures of value.

I have thought it best to confine my paper to a few typical buildings, which I know all about, and to discuss these in detail, rather than to tabulate figures more or less accurate from a large number of buildings, where all the conditions were not obtainable.

The methods by which the figures have been arrived at, are of course, of the highest importance, in fact, they entirely determine the value of the results.

In all cases except where otherwise stated, the kilowatt hours supplied by the isolated plant have been obtained, either from hourly and daily reports of ammeter readings, or from wattmeter readings.

The other items of coal, water, oil, waste, lamps, labor, etc. have been furnished me by the owners, from their books, or in one case, by the agent in charge of the building. I have laid great stress on the necessity of obtaining accurate results, and as the question was one of interest to all who run plants, I experienced little difficulty in obtaining access to the books.

As the question of distribution and character of load has a considerable influence on the fuel consumption and the labor charge, I have included load diagrams from many of the plants, obtained as stated either from logbooks and hourly records, or from personal readings.

Before proceeding with the figures and diagrams, a definition and an explanation are necessary. What is the "cost of electric lighting or electricity" in a building plant? In my opinion, the cost of electricity in a building plant, is the difference between the cost of supplying the other requirements of the building, (the electricity being purchased outside), and the cost of supplying the other requirements of the building and electricity from private plant. The cost in all cases to include interest and depreciation. Interest and depreciation are reckoned at 5% each. Money is invested in a plant and can generally be replaced at an interest charge of 5%. The plant may be considered worthless in fifteen years, as an average case, and enough must be put aside yearly to repay this amount of its cost. 5% per annum with interest at 5% will equal the original investment in 15 years.

No cost per kilowatt hour can be definitely fixed, as every case must be determined for itself. For instance; the cost of electricity where steam is obtained from a central service may be quite different from the cost where boilers are operated. The addition of the electric plant in the former case may cause a large and expensive increase in the labor and rental charges while in the latter case no increase in these items might be necessary. The cost of electricity in a building, where high-speed elevators, refrigerating and laundry machinery are operated, in addition to the electric plant, is much less per kilowatt than it is in a "loft" building, where skilled supervision was not necessary before the introduction of an electric plant. The necessity of steam for heating has an important influence on the cost, and on this account, figures for buildings in New York would be of little value in New Orleans or Toronto.

I have chosen for discussion in the paper, data from hotels, office buildings, loft buildings, department stores and apartment houses.

Considering the hotels, and with proper respect to height, the tall one first: This hotel is 15 stories in height and is an example of the finest and best in the hotel line, although the rapid improvement and development of the past two years has made even

this modern plant slightly old-fashioned. It contains 11 electric elevators, four of which are high-speed screw elevators, compound engines, directly connected to generators, water-tube boilers operating at 125 lbs. pressure and a complete refrigerating and ice-making outfit, besides all usual apparatus and laundry machinery. One of the proprietors, very courteously placed his logbooks at my disposal.

In Fig. 2 are shown curves of hourly variations in the demand for light and power. This curve does not include elevator power merely the power for motors as laundry, kitchen, office, etc. The elevator load being of the usual character and similar to that shown in Figs. 6 and 8. Curves, for which I am indebted to the engineer, of average daily lighting load are shown for six months of 1897, in Fig. 3.

The cost of the electricity in this hotel, is the difference between the cost of operating plant with the electric generating apparatus and the cost without.

A depreciation and interest charge on about one-fifth of the boiler and steam piping should be added, as about four-fifths of the boilers installed would have been necessary without the plant. This amounts to about $500 per year.

Without going into the question of what the total cost of operating this plant is, there are certain items, such as lamps, cylinder and machine oil, engine and dynamo repairs and packing which may be directly charged to electricity. These amount to $3000. In the item of labor, if an electric plant were not in operation, 1 engineer, 2 firemen and 2 oilers could be dispensed with—about $3600 per year.

The question of amount of coal used per kilowatt hour in this plant depends entirely on the season and the amount of current supplied. If the exhaust steam from the engine is insufficient to meet the heating requirements, additional lighting makes no appreciable change in the amount of coal used. During warm weather or when the steam for lighting exceeds the amount required for heating, the amount of coal used increases in proportion to the electricity supplied. The curve of coal per kilowatt hour would therefore be similar to the curve of steam generation, *i. e.*, it would be almost straight, until the heating requirements were met, and would then rapidly increase for additional kilowatt hours supplied. This variation is illustrated by the following table [See next page.]

From April 25th to May 2nd, the hotel lighting was supplied by the Edison company, the elevators and motors being supplied from the isolated plant. From May 4th to May 11th, the whole installation was supplied from the isolated plant. As the temperatures for the two weeks were nearly the same, the work, other than the lighting, may be considered about constant, and the variation in the average amount of coal used charged to the electricity supplied.

In March and January coal per additional kilowatt hour may be estimated in a similar manner, although as the Edison service was not used, the differences are not so great and the deductions are therefore liable to large error.

Interval.	Ampere hours.	Kilowatt hours total.	Coal lbs.	Coal per additional K W. hour	Average load kilowatt.	Average Temp. at 6 P.M.
May 4–11	5439 x 24	15200	221000		83	57° F
April 25–May 2	2313 x 24	6400	195000		28	61½° F
Difference	3126 x 24	8800	26000	2.95		
March (2–6) (14–18)	7140 x 24	20250	339000		105	43° F
March (6–14)	6569 x 24	18600	329c00		97	44½° F
Difference	571 x 24	1650	12000	7 25		
Jan. (15-22) (29–Feb. 5)	12719 x 24	36000	608000		107	32½° F
Jan. (1–8) (22–29)	11899 x 24	33660	593000		101	31½° F
Difference	820 x 24	2340	15000	6 4		

This table shows the kilowatt hours supplied during 2 sets of 7 days each in May, 2 sets of 8 days each in March and 2 sets of 14 days each in January. As the work done other than the electrical is about constant during any pair of sets of days the difference in amount of coal used is chargeable to the electricity supplied. Inspection of the table shows that throwing the lighting load on the Edison service from April 25 to May 2nd, reduced the coal used by less than 3 lbs. per K. W. hour. As the actual coal per K. W. hour in the non-heating season is between 3½ and 4 lbs. it is evident that during the period, April 25th–May 2nd, the exhaust steam was insufficient to heat the building and also that the additional 8800 K. W. hours supplied, after the Edison supply was cut off from May 4th to May 11th, were not a direct charge on the coal pile. The results in March and

January are as stated, subject to large errors but they serve as an indication of the influence of heating. It is evident from the table that in January and March the exhaust was in excess of the steam required for heating, while the contrary was the case from April 25th to May 2nd, when the Edison current was in use. The coal chargeable to electricity is derived as follows:

The current supplied from April 25th to May 2nd (excluding Sunday) was approximately equal to that supplied from May 4th to May 7th and also from May 8th to May 11th. By combining these figures and eliminating the electric factor, a rough idea of the constant requirement is obtained and proves to be about 24,000 pounds of coal per day, exclusive of electricity at this mild season.

Equal amounts of electricity were supplied during two periods of 13 days and of 12 days in July.

The difference in the amount of coal burned was 22,000 pounds. As the total amount of electricity supplied was the same, this difference is evidently the constant quantity of coal used, exclusive of that required for electricity. The constant for July is therefore about 22,000 pounds. This method is subject to considerable error, but by comparison with other of the non-heating months the figure obtained has been shown to be about correct.

In the same way the constant for March is fixed at 35,000 pounds coal per day. That for January is about the same.

The coal per kilowatt hour in each of the above months is the difference between the total coal used and the constant coal requirement, divided by the number of kilowatt hours.

The total coal used in 25 days in July was 700,000 pounds. The constant demand 550,000, leaving 150,000 pounds for the electricity, and as 41,500 kilowatt hours were supplied this gives a figure of 3.62 pounds per kilowatt hour.

In January, in 14 days, 608,000 pounds of coal were used, and subtracting the constant coal, *i. e.*, 14 $\times$ 35,000 pounds equals 490,000 pounds, leaves 118,000 pounds for 36,000 kilowatt hours or 3.27 pounds per kilowatt hour. The average for the year will not exceed 3.4 pounds per kilowatt hour.

The total kilowatt hours per year exceeds 825.000. The cost of electricity in this hotel is therefore,

Coal	$4,075
Labor	3,600
Sundries, (lamps, repairs, supplies, etc.)	3,000
	$10,675
Interest and depreciation	3,000
	$13,675

Cost per K. W. hour exclusive interest and depreciation	1.3	cents.
" " " " inclusive " " "	1.66	
Coal per K. W. hour	3.4	pounds.
Cost of coal per K. W. hour	0.5	cents.

By the introduction of an automatic stoker and a storage battery and the use of cheap coal with proper provision for ensuring good combustion, this figure could be further reduced, but it is pretty nearly low water mark for electricity, as supplied from an isolated plant.

A smaller hotel of which the data follows has had a plant in operation only a few months, but as a log of coal, amperes and other plant items is carefully kept hourly, its discussion will be of value. This hotel is 75x100 feet with an L 25x100 feet, seven to eight stories.

The electric plant is too small for the work, but it was installed with two understandings: 1st, that the Edison current was to be on hand for emergencies; 2nd, that no signs were to be installed. Four signs have been installed and the Edison current removed. I merely insert these facts as an example of the difficulty in meeting conditions. The plant consists of

Two H. T. 4′ × 12′ 40 H. P. boilers.

One 12′ × 7′ × 10′ Worthington elevator pump.

One 4½′ × 2¾′ × 4′ Worthington return pump.

One house pump.

One 35 K. W. engine generator combination.

One 3-ton absorption Steele & Condict refrigerating machine.

Steam is supplied to kitchen, elevators and other pumps, to engine and ice machine.

The previous cost of heating and elevator operation was

Coal, 2 tons per day, $4	$2,900
Labor, 3 men	1,320
Sundry supplies	150
Water (for purpose of comparison)	constant
	$4,370

In order to determine the cost of electricity the above cost should be reduced by $770 on account of saving obtained by use of small coal.

On this basis the cost of heat and elevator operation was \$3,600. The cost of installing generating and refrigerating plant was \$5,000—a plant to meet the present conditions and maintain a proper reserve would have cost \$7,500, on which an interest and depreciation charge of \$750 is ample.

The present cost of operation is

Coal, $3\frac{1}{2}$ tons per day, at \$2.75	\$3,500
Labor, 4 men	2,000
Oil, waste, lamps (estimate)	300
Ammonia	50
Water, constant	500
	\$6,350
Interest and depreciation	750
Total cost	\$7,100
Previous cost	3,600
Cost of electricity, refrigeration and steam for kitchen	\$3,500

The light used averages 2,500 ampere hours per day at 118 volts equal to 2,150,000 — 16 C. P. equivalents in a year.

The refrigeration varies from $1\frac{1}{2}$ to 2 tons per day, ice melted equivalents = 640 tons per year.

The cost of these two items at $\frac{3}{10}$ cents per 16 C. P. equivalent and \$3 per ton for ice would be \$8,370 per year.

This shows a net saving of about \$5,000 per year by the isolated plant. To obtain a figure for the cost of electricity in this plant, the cost of water used for condensing the ammonia gas into liquid ammonia, the interest and depreciation on the cost of refrigerating apparatus and the cost of ammonia must be deducted. These amount to \$650.

By a test made on the refrigerating machine, I found that 50 pounds of steam per hour per ton actual refrigeration was sufficient to allow, and on this basis the coal used for refrigerating amounts to about 100 tons or \$275 in the year—the hours of operation being averaged from the log records. The labor increase may be divided between the electric and refrigerating apparatus in proportion to the coal used *i. e.*, four-fifths and one-fifth.

The cost of electricity supplied is therefore:

Coal, 450 tons at \$2.75	\$1240
Labor, \$660 x $\frac{4}{5}$	530
Oil, waste and lamps	275
Water	50
Interest and depreciation	550
	\$2645

Cost per K. W. hour is $\frac{2645 \times 20}{2,150,000}$ .... 2.45 cents

Coal per K. W. hour $\frac{900000 \times 20}{2,150,000}$ .... 8.37 ponnds

Cost of coal per K. W. hour........ .... 1.17 cents

The load curves shown in Fig. 4 are characteristic of this type of hotel, or more properly of the restaurant, and in general outline will be duplicated in any restaurant having illuminated signs and decorative lighting. Its characteristics are, a steady light load during twelve hours and a steady heavy load during ten hours—conditions best met by two units, or in some cases three.

As an example of what an engine can do when necessary, it is worth noting that this plant has run on an average over 20 hours a day for the past four months, with an eight-hour daily overload of from twelve to twenty per cent. The use of a force pump system of oiling with filtering device etc. on the engine, has amply proven its value by reducing the consumption of machine oil to less than one quart per day, about 0.00025 cent per K. W. hour.

From the hotel to many apartment houses the change is more nominal than real, as frequently in those of the more modern type electric light, refrigeration and steam heat are distributed throughout "free" to the tenants and a large restaurant on the ground floor makes the resemblance complete. There are, however, apartments having a load quite distinct from the hotel. In these, electric light is only supplied from 5 o'clock until 12 or 1 and during the rest of the time tenants burn gas, which they pay for directly. As most of the cooking is done by gas ranges, the small additional charge for light used is not objectionable. Elevator service is necessary at all times, or at least until late at night. Formerly these elevators were steam-hydraulic, but latterly the electric type has predominated. Where light is furnished free, an isolated plant is installed (unless the building is in speculative hands) but when light is not free, a plant is seldom installed. In none of these plants have I been able to obtain a complete hourly record of lights burned, but from several of the same size I have obtained careful estimates, which, as they agree very closely may be considered approximately correct. The coal, labor and similar items are exact and are taken from records. I will instance two, which are typical of their kind.

The first is a seven story apartment house, 100 x 100 feet, with 38 apartments, a small restaurant, having two hydraulic passenger elevators and one hydraulic freight elevator and a belted electric light plant. The latter operates only at night and until one o'clock. One engineer and a fireman during the day, and one man at night constitute the entire staff, and as the repairs have been nothing for the past five years, and as the service has been thoroughly satisfactory, the staff is evidently sufficient.

The total cost of operating the steam and electric plant is:

Coal	$1642
Water (estimated) 25c. per ton of coal	90
Oil, waste, etc	72
Engineer, fireman and assistant	2390
Lamps, ashes and repairs	115
Total cost	$4309

A similar apartment house having one hydraulic elevator and steam heating and outside electric service, costs:

Coal (for heating and hot water)	$1157
Labor (2 men $12 and 10 per week)	1144
Sundries (estimated)	100
	$2401

The cost of elevator and light service is therefore about $2,000 per year. The total installation is 900 incandescent lights and the average load from five until twelve, is 500 lights reduced in summer to about 350. The total number of kilowatt hours supplied by this plant is over 55,000. The cost per kilowatt hour is therefore, 3.8 cents, exclusive of interest and depreciation, which add 0.9 cents or a total of 4.7 cents per kilowatt hour. The coal per kilowatt hour is about 7 pounds. The cost at present wholesale rates would be over double the above figures, *i. e.*, about 9½ cents per K. W. hour from the central station.

In another apartment house of the same size, a low pressure heating boiler is used with electric elevators. The cost in this plant, exclusive of light and elevator power was:

Coal	$730
Labor	924
Sundries (estimated)	46
	$1700
Electric Elevators (power)	350
	$2050

In an apartment of the same size:

Coal	$2190
Labor	2100
Sundries (estimated)	300
	$4590

The cost of heating and electricity for elevator and lighting from the isolated plant was $4590.

Deducting $1,700, found as the cost in the preceding instance of heating and supervision, from $4590 leaves $2900 as the cost of elevator power and lighting. As the power for an electric elevator from the central service would not cost over $250 per year, a K. W. hour of light from this style of plant is evidently more expensive than from one with hydraulic elevators and an electric light plant, and unless some means of equalizing the load is employed, this is undoubtedly the case.

I am watching with interest a storage battery plant installed last month, and hope that therein lies the salvation of the electric elevator in apartment houses, although another means, *i. e.* electric heating, offers many advantages. In apartments smaller than those mentioned, isolated plants are installed in connection with hydraulic elevators, but low pressure heating and outside service with electric elevators is cheaper and better when it is available.

A number of experiments are being made with gas engines in apartment houses and I hope some of those present will give us some definite data regarding them. From figures I have obtained, however, the results are not very promising.

The conditions in department stores resemble those in hotels and hotel apartments. As in the hotel, there is a 24-hour demand for light with a peak from 4 until 7 o'clock, but in the store the peak drops abruptly at this time, while in the hotel the load either remains stationary or continues to increase for many hours.

Characteristic curves of a typical plant are found in Fig. 1, the data having been obtained from R. H. Macy and Company, through the courtesy of Mr. Straus and his engineer, Mr. Brennan.

As in the hotel, these stores use large quantities of steam for other than electrical purposes—in Macy's there are 17 elevators (steam and hydraulic), two restaurants, a laundry, a cash blower engine of 55 I. H. P. and a small engine for glass cutting. This varied use renders it difficult to obtain the cost of electricity, but I am able to present figures from a similar building where elec-

tricity for lighting was formerly bought from the central station and where the other conditions have not varied materially since the installation of the plant.

The load in this building, although there are fewer lights and smaller load maxima than in Macy's, about equals the total in the latter on account of several display signs which hold up the average until 10 nightly.

The additional coal burned since the installation of the plant last year is less than 925 tons (pea).

The total kilowatt hours supplied from the plant was over 200,000 and the cost of installation, including additional boilers, was not more than $20,000.

The cost of electricity was

Extra labor, 1 night engineer, 1 fireman, 1 helper and 1 electrician (6 months)	$1,200
Oil, packing, waste and lamps	450
Coal, 925 tons, at $3	2,775
Extra water (about)	250
Repairs	
	$4,675
Interest and depreciation (6 months)	1,000
Total cost	$5,675
Cost per kilowatt hour less than	2.85 cents.
Coal per kilowatt hour.	9.25 pounds.
Cost of coal per kilowatt kour	1.45 cents.

There are, unfortunately, no figures yet for the summer months, but the yearly average will not differ greatly from the above as the apparatus previously in use, supplied nearly enough exhaust steam for heating the building. This can be readily seen from the large amount of coal required per electrical kilowatt hour in the heating season.

It is of interest to note that the amount of the electric light bill for the six months of '97-'98 corresponding to those listed was greater than the total present cost of light, heat and power.

Mr. J. Little, of 15th Street and 6th Avenue, has put his figures in my hands and it is regrettable that no hourly record of current is kept. The number of lights used does not vary greatly from day to day in a building of this character, except for a decided drop in dead summer season. I include these figures, as they are obtained from a store, small compared with the one just mentioned.

Mr. Little has one hydraulic elevator and a large number of

incandescent and arc lights, and as these lights are used for display advertising, the figure given me of 125 amperes average burning for 14 hours per day, may be taken as approximately correct, especially as I have partially verified the figures. I have reduced the above, 20% for safety against underestimating kilowatt hour cost. The total kilowatt hours on this basis is about 50,000 per year.

The increases caused by electric light plant were

Coal, 320 tons, at $2.55	$815
Labor	824
Incidentals, including water	230
Total increase	$1,869
Interest and depreciation	250
Cost of electricity	$2,119
Cost per kilowatt hour less than	4.1 cents.
Coal per kilowatt hour	12.8 pounds.
Cost of coal per kilowatt hour	1.6 cents.

Mr. Little is considering the advisability of a large sign, and if he installs one, the additional cost will be merely that of the extra coal and sundries and additional wear and tear on machinery.

In the office building the load line is entirely different from the hotel or store, in that there is no load to speak of after 7.30 o'clock, while the hotel load is at its maximum at that time and the load peak is not so pronounced.

In the Hartford building, corner of 18th street and Broadway, a most careful and complete system of records is kept by Mr. E. Fred, the chief engineer, under the direction of Mr. Stephen Tyng, the agent in charge. Account is kept of everything in this building, even to the number of minutes the elevators are in actual operation, and through the courtesy of these gentlemen I am able to accurately determine the cost of electricity in this building.

Fig. 9 shows curves of daily load for each month in the year, the lower being the general average for bright days, the next, the general average for dark days, and the highest, the day with the maximum peak for the month.

The total *lamp* hours of light in one year were	2,000,456
The total *horse* power hours of power in one year were	77,869
The total H. P. hours light and power	211,233
Total amount of coal used	2,025,700 pounds.
Coal per E. H. P. hour	9.6 pounds.
The *total* coal per E. H. P. hour in summer was	9.4 pounds.
The *total* coal per E. H. P. hour in winter was	11.7 pounds.

To obtain the cost of electric light and power as in hotels, the cost of heating and operating this building without reference to light and power, must first be determined.

The coal for heating such a building would be about 210 tons a year. To retain the same class of service as at present, one engineer could be dispensed with. This leaves 1,600,000 pounds of coal chargeable to the electric plant and one engineer to which must be added oil, waste, etc., Edison and fixed charges.

The cost of electricity in this building is

Coal	$2,150
Labor	950
Lamps	200
Sundry supplies and ash cartage	400
Interest and depreciation	1,500
Edison charge (about)	1,800
	$7,000

The cost per K. W. hour .... 4.37 cents.
The coal per K. W. hour .... 9.4 pounds net.

The cost on central service would be 9.5 cents per K. W. hour for light, and 4.5 cents per H. P. hour for power, and the total $12,000 for light and power, a balance in favor of the isolated plant of $5,000 per year above interest and depreciation.

The use of a storage battery as an equalizer and to take the night load would reduce the total above, to about $6,250 per year, reducing the cost per K. W. hour to 3.9 cents. These figures include interest and depreciation charges.

It is interesting to note *en passant*, that the amount of time the elevators are actually using power varies from one-fifth to one-sixth the total hours in commission and that the power used in the fields (five-sixths of which is wasted) amounts to about twice the power used to operate the cars.

The next buildings to be considered are those termed loft buildings, a class which in the modern form is a direct consequence of the tendency toward concentration, and is of rapidly increasing importance. These buildings which are beginning to cañonize upper Broadway (if one may use the term) as the office buildings have the lower portion, are from eight to twelve stories high, and from 100 to 200 feet deep, with their lower floors devoted exclusively to show-rooms and their upper floors to show-rooms combined with manufacturing. They are invariably of fire-proof construction, and on account of the small compara-

tive cost of insurance and the large rentable space for a given ground area, besides the greatly increased conveniences, have practically driven the older five and six story buildings out of business.

These buildings require electric power for elevators and on the various floors for motors, used to drive sewing machines, presses and similar apparatus. Electric light is not generally used in great quantity in the upper portion, but in the basement and first two or three floors, a considerable amount is used for decorative effects, and lighting made necessary by the height of surrounding buildings. In addition to these demands there is another demand that has heretofore been met by gas, *i. e.* direct high temperature heat applications, for such purposes as irons, presses, ruffling irons, etc. With current at central station prices and the present keen competition in business, electricity cannot compete with gas, but to the isolated plant, the steady load of the electric heater is a welcome addition, which proves sufficiently profitable to make it worth while, even at a cost equal to gas. I installed a plant in such a loft building about eight months ago, and have received daily reports since the commencement of operation. The results are of interest, as they deal with a field that has been claimed by the central station men, as their very own, on account of the light average load factor of electric elevators and the comparatively short duration of the lighting load, as compared with that of hotels or office buildings.

This building is a ten-story loft building, 55 x 200 feet, having two passenger and two freight elevators (all electric) and an electric pump.

The 10th, 8th, and 7th floors are used exclusively for manufacturing. The 9th and 3rd are divided between manufacturing and salesrooms and the remainder are all salesrooms, storage and shipping departments. The first two floors are beautifully lighted, by over 500 incandescents, and previous to the introduction of the plant, none of the other floors was lit electrically, except in a few salesrooms. Two five-H. P. and one three-H. P. motors and a half-dozen fans constituted the whole electrical equipment of the tenants. Notwithstanding the paucity of electrical apparatus, the cost of electric power (including elevators) was $2500 per year and the electric light cost a thousand dollars more, though the care with which it was used may be seen from the fact, that no tenant was able to get the discount allowed for more than

"one hour burning per day per lamp installed." In addition to this the gas bills amounted to about $700, principally for heating, and a small boiler was run on the top floor for dyeing, and running a small engine.

The building is exposed on the north above the fourth floor, and steam from a 150 H. P. Bigelow boiler supplied heat during seven and a half months. One man fired the boiler and half looked after the elevators.

The cost of heating the building and supervision (exclusive of elevator repairs, and other incidentals not germane to this subject) was $1600 per year (average).

The total cost of light, heat and power was about $5800 per year.

In October the electric plant was started, but on account of existing contracts, etc., and troubles incident to a change from 120 to 240 volts, the plant had not settled down to regular work before January.

The plant consists of three 33 K. W. direct-connected sets, supplying light and power from the same bus-bars at 240 volts; as there was only room for the old boiler, a breakdown connection was arranged with the street. The meter system was abolished, as one of the objects was to make the tenants anxious to stay in the building, and it was desirable that all possible friction should be avoided; they were therefore allowed to use unlimited light for the amount of their previous bills. Electricity was introduced in place of gas for heating irons and presses, and over 500 additional lights were installed, the additional light and electricity for heating being supplied at the cost of gas. Steam was supplied to the top floor for feather steaming, dye vats and engine.

The electricity now used by the tenants is about four times that used previously to the plant installation, and that the benefits are appreciated is shown by the fact that every tenant has signed a contract for two and a half years.

The cost of electricity in this building varies from 1.75 cents per K. W. hour in heating weather, to 2.07 cents per K. W. hour in non-heating weather, exclusive of fixed charges, which amount to $\frac{6}{10}$ of a cent additional.

The total K. W. hours in January were 11,550, in April, 10,250, of which about 2,500 K. W. hours per month are due to elevators.

The total coal used per K. W. hour in January was 13.6 pounds.

The total coal used per K. W. hour in April, 11.6 pounds. The increase due to heating, about 15 per cent. If the coal previously used for heating is deducted, the additional coal per K. W. hour, *i. e.* the coal used for electricity, was about 6.8 pounds in January and 8.7 pounds in April.

The coal used in May per K. W. hour was about 11 lbs. If an equal amount of electricity to that at present supplied were purchased, the cost on the central station service, would be $8200.

The balance in favor of isolated plant, on basis of equal amount of electricity supplied, is over $4000 per year in this case.

This balance would be increased by the installation of a storage battery, costing about $5000, avoiding the necessity of Edison service and by furnishing absolutely steady load to the engine, would reduce the coal used by nearly twenty per cent. The night service, which would be furnished by the battery, is of such small moment that the coal used for its supply would hardly be calculable and would certainly not exceed a few tons. The ten per cent. fixed charges on the battery would be overbalanced by the present cost of Edison service, and the coal saved would be net gain.

I have entered into the details of this plant to a perhaps unwarranted extent, but I think several important facts are brought out clearly.

First:—An isolated plant can be operated at a profit at rates lower than those of the central station, even on a wildly fluctuating elevator load, and a light load of short duration.

Second:—That the isolated plant service is a benefit to both tenant and owner.

Third:—Through the isolated plant, and only by this means can the use of electric heating appliances be brought to its full development.

Fourth:—The central station cannot compete, in so far as cost is concerned, with the isolated plant, where skilled attendance is otherwise required, and steam heat is necessary.

I shall have more to say on this fourth point later.

Curves are shown in Fig. 10 of the general day load of steady light and power in this plant, and in Fig. 6 a curve from five-second ammeter readings of lights and elevators is typical of this class of service. Figs. 7 and 5 show daily loads for months of January and April. On the same page is shown the total load of

a combined loft and office building which is spoken of later on.

The loft building is possessed of one advantage, which in a measure compensates for the extreme irregularity of the elevator load. The electricity used in summer for lighting, *i. e.* the non-heating season, is extremely light when compared to the winter load, so that the amount of steam and water wasted is not so large, proportionately, as it is in a hotel plant where the demands are more evenly divided between the seasons. This condition is largely modified by motor and heating load.

I am unable to present complete figures on a small office building, as I have not found one in which hourly record of lights burning is kept.

The coal, oil and other items have been carefully noted in several, and as the number of lights burning in a small building does not vary greatly from hour to hour, or day to day, I will include the figures from one.

This building is thirteen stories, 50 x 30, and contains two drum elevators, two engines belted to 40 K. W. generators and one H. T. boiler. Night service is supplied by New York Light, Heat and Power Co.

The coal used varies from 1863 pounds in summer, to 2007 pounds in winter per day.

One engineer and one fireman run the plant, and the cost of heat, light and power, exclusive of night lighting and power, is less than $2500 per year.

Labor	$1250
Coal	750
Water	50
Oil, waste, lamps, sundries and ashes	250
Repairs (estimated)	100
	$2400

The cost of electricity in this building is ($2350 plus central station charge of $180 plus $500 interest and depreciation) less (labor $624 plus coal for heating, $380) = $2,025.00.

I have been in this building many times at all hours during the day and have never seen the ammeter register below 35 amperes on one side of the system. The engineer, who has been there several years, states the average lighting during the day to be 120 lights, and the maximum 350. It is therefore, perfectly safe to assume that the average current is 35 amperes and the yearly kilowatts 22,000. The power required by the two elevators is not less

than 18,000 kilowatt hours per year, and the total power at least 40,000 kilowatt hours per year. This makes the cost per kilowatt hour, including interest and depreciation, 5.06 cents, excluding interest and depreciation, 3.81 cents. The coal per kilowatt hour is 7.25 pounds and the cost of coal per kilowatt hour is 0.925 cents.

These figures are, of course, approximate, but are correct within 10 or 15 per cent.

The cost of operating buildings without electric plants is even more interesting than the cost of operation where the plant has been installed.

I have noted in each instance, the cost at the present rates, of electricity in equal amount to that supplied by the plant, but the figures of the defunct Wool Exchange and of the Sohmer building, one containing a million and a half cubic feet and the other half a million, will confirm these estimates. Neither of these buildings has electric plants but each has two electric passenger elevators and one electric freight elevator.

In the Wool Exchange, the Edison company supplied 822,063 -16 C. P. equivalents of light, 38,375 H. P. hours of power, at a total cost of $7,700. Under the new rates, this cost would be reduced to $6,000 total, or as 70,000 K. W. hours were supplied, about 8.6 cents average price per K. W. hour. The cost of heating, operation of pumps and supervision (one engineer and one fireman, six months,) was $3,100. The cost, therefore, at present rates would be over $9,000.

Contrast this with the loft building cited, where, with the same cubic contents and over 100,000 K. W. hours supplied annually, the total cost is less than one half the above.

Although it is customary to speak of the elevator load as of comparatively small importance, in the Sohmer building it amounts to two-thirds of the total electricity supplied to the building.

In the loft building, on account of the electric heating apparatus and motors, it amounts to about one-fourth of the total quantity supplied. In many of the office buildings, it exceeds the lighting load, so that it is not a factor by any means despicable. It has one advantage to compensate for its momentary fluctuating character, which is, that owing to the fact that the bulk of weight travels downward at night, its requirements are not so severe when the period of heavy lighting commences as

TABLE.

SHOWING COSTS AND COAL PER K. W. HOUR.

Type of Building.	Type of plant.	COST PER K. W. HOUR. Including Int. and Dep.	Excluding Int. and Dep.	Coal per K.W. hour.	Cost coal per K. W. hour.	Kind of load.	Approximate annual total K.W. hours.	APPARATUS SUPPLIED.
Large Hotel......	Compound	1.66 cents	1.30 cents	3.4 lbs.	0.50 cents.	Fluctuating.	825000	11 Elevators, Kitchens, Refrigerating and Laundry Machinery, Ventilating and Heating and Lighting, Pump.
Small Hotel,.....	Simple	2.45 "	1.94 "	8.37 "	1.17 "	Steady.	100000	2 Elevators, Kitchens, Refrigerating and Heating, Pump.
Apartments	"	4.70 "	3.80 "	7.00 "	0.88 "	"	55000	3 " " Lighting " " "
Department Store.	"	2.85 "	2.35 "	9.25 "	1.45 "	"	200000	4 " Cash Blowers, Laundry, Lighting & Heating, Pump
Small Store.......	"	4.10 "	3.60 "	12.80 "	1.60 "	"	50000	1 " Lights.
Large office bldg...	"	4.37 "	3.42 "	9.40 "	1.36 "	Fluctuating.	158000	4 " " Ventilating, Heating.
Small " "	"	5.06 "	3.81 "	7.25 "	0.93 "	"	40000	2 " " Heating.
Loft building.....	"	2.60 "	2.00 "	8.00 "Appr	1.02 "	"	100000	4 " Engine, Lights, Heating, Pump, Motors, Dye Vats, El. Heaters.
Loft and office....	Edison	Power 6.66 cents Light 17.20 "	....	....	....	....	30000 15000	3 Elevators, Lights, Pumps, Heating.
Loft building. ...	"	8.6 "	....	....	....	....	70000	3 " "

they are in the morning hours, and about the same amount of power is required from hour to hour and day to day.

In the Sohmer building, where the lighting factor would seem negligible, due to its exposed condition and small depth (30 feet), the cost of electric power for two passenger and one freight elevators, and electricity for lighting is over $3,900. The cost of heating and supervision is over $1,200—a total of more than $5,100, or $700 a year more than a building nearly four times its size, containing an isolated plant.

The total energy supplied in this instance amounts to over 45,000 K. W. hours, 30,000 for power for elevators and pump, and 15,000 for lights. The cost per K. W. hour for light was 17.2 cents, and for power, 6⅝ cents.

I am now installing an electric plant in this building, with storage battery auxiliary to take the fluctuation and night load. The total cost will be under $10,000, and the reduction in annual expense will certainly exceed $2,500—an excellent return on the investment. The cost per K. W. hour should not exceed four cents, everything included.

This building is 30 x 100 by 13 stories, and is exposed on all sides, so it may be considered to offer the most advantages to the central station, with the exception, of course, of the small private houses and small loft buildings, where, without a block system, no rival can enter. The curve of elevator and light load on a bright day shows the character of the service.

As an example of the large part that steam heating takes in the expense of operating a building, the Franklin building on Murray street is of interest.

During the months of November and May the coal per K. W. hour for electricity delivered was little over seven pounds, but during the months of December, January, February and March the coal averaged over 20 pounds. Evidently, this difference was not due to the quantity of current delivered, and in fact, the coal used would have been required whether the plant was in operation or not.

I have not given any figures from very small buildings, as the question of cost seldom enters: other items, such as convenience and space, are more important and decisive.

It would appear from these figures that the central station had no mission to fulfil, except that of supplying breakdown service and service to small buildings, and it seems hard to reconcile this

with the enormous annual increase in the gross receipts and net returns of the central stations.

While it is true that a properly designed plant will, under good management, furnish current in a building of fair size at a cost of from 2 to 4.5 cents K. W. hour, everything included, it is not always advisable to install a plant. In many clubs, restaurants and other places, where quiet is absolutely essential, or where space is limited, or valuable, a saving of a few thousand dollars is not of sufficient moment to make it worth while.

There is another large class of buildings where the central station has a practical monopoly of the field at the present. This class is the loft or combination loft and office building, erected purely for speculative purposes. I do not mean by this, built cheaply, but for sale. Typical examples of these buildings are found along Broadway, and are similar to the loft building cited in this paper. These buildings are seldom more than half full for the first year or two, and are generally sold before the third year expires. Light or power are never furnished free. The elevators, on account of the comparatively few tenants, are inexpensive to run on the central service. The object of the speculative builder is to build the best building possible for the least money, and to keep down his operating cost as low as possible. In selling his building a lump sum is fixed, based on the estimated cost partially, but to a great extent on the operating cost, and by getting his current from the central station for elevators, and employing a cheap man to run a heating boiler and look after the elevators and machinery, the builder obtains a low operating cost and avoids an additional initial expense.

This class of building is comparatively new, and the possibilities of returns from the tenants have not been fully appreciated, but I have little doubt that a few more examples, such as the building cited in my paper, would convince the investor and through him the builder, of the advantage of installing an electric plant, thus reducing the operating cost by the receipts from tenants, but up to the present time this has not been the custom.

Personally, I do not believe that the central station receipts will continue to increase at the present rate, unless a supply of steam for heating, as well as electricity for power, can be furnished. It is a noteworthy fact that a great number of the largest office buildings down town are buying steam from a central station to run electric light engines and pumps, using the exhaust steam for heating.

The advantage that the steam supply company has over the electrical supply company lies in the fact that the former sells steam at the cost of coal plus labor, which in all office buildings is a large proportion of the total cost. The smaller the building the larger the proportion the labor bears to the rest. The electrical company cannot, on the other hand, hope to sell its electricity for much more than the cost of the extra coal, oil, waste, etc., and interest and depreciation charges on the plant, that would be necessary for local supply. The labor, is in all but very few cases, made necessary with or without the plant, by the need of skilled attention for elevator and machinery.

The cost of electricity in the isolated plant has been shown to vary from two to five cents per K. W. hour. A study of the clear and well written report of tne Edison Electric Illuminating Company of New York, is well worth while. From the figures given in this report, I find that 22,777,000 K. W. hours were delivered last year, at an average price of 10.6 cents. The actual cost to the Edison company (that is operating expenses divided by K. W. hours supplied) is about one-half this sum. This latter, of course, does not include interest or depreciation on the investment. The average price therefor, at the present time, is from two to four times that of the isolated plant, and the cost of manufacture from one to two times the cost in the isolated plant, and the reason is not far to seek.

The isolated plant is never installed unless the conditions ensure comparatively large average use of the current and small additional trouble. On the other hand, the central station is obliged under the terms of its charter, to supply anybody within a hundred feet of its mains and the immediate consequence of this is, a large amount of unprofitable business. The average load for every hour of the twenty-four for the whole year, is about 2,600 K. W., while the maximum is nearly 12,800, requiring a large excess capacity over that generally used. As a matter of fact, the total capacity of the system in kilowatts is stated by the report to be over seven times the above average. As this excess capacity extends to the mains, as well as the generating apparatus, the proportion of fixed charges to cost of operation must always be enormous, although the storage battery will, to a certain extent, help them out.

I have little doubt that a continual decrease in the prices will be made by the central station, as their business increases, but a

similar decrease is going on in the isolated plant, both from the increase in knowledge of the requirements, and the increase in the uses of electrical apparatus, uses which are largely stimulated by the cheap supply. I also believe that there are very few plants, that would not welcome the central supply of steam.

A continued erection of large buildings in a congested area will inure to the advantage of the central steam supply and for the reasons above given, to the disadvantage of the central electrical supply.

Only one office building in ten, of modern construction, takes its current from the central station, and with the large loft buildings, the story will be the same, as soon as these buildings pass into the hands of investors.

The department stores, hotels, large restaurants and apartment houses (where light is given free) have already found the isolated plant to be the cheaper and the continued disappearance of small buildings will increase these conditions, unless the central station companies can discover elevators that will take care of themselves, or incorporate with the supply of electricity, a cheap supply of steam for heating.

Discussion.

The President:—The paper is now before the Institute for discussion.

Mr. H. Ward Leonard:—This subject of the isolated plant is a very old one and has a good many points in it pro and con. There has been no very radical change in the cost of production of energy in isolated plants over quite a period. I remember about twelve years ago I secured a great abundance of statistics covering probably three hundred isolated plants in the west, and although the cost varied, as, of course, such figures always will, the statistics were based upon answers to a very large number of questions that were framed with the idea of getting accurate figures, and the owners in those days were I think perhaps a little more interested in the results than they are now; at any rate they very gladly went to considerable trouble to give me the figures. I remember that the cost at that time, that seemed to be attainable, in a well installed plant was about a quarter of a cent for 75 watt hours, which would be in the neighborhood of about $3\frac{1}{3}$ cents per kilowatt hour, and it seems to me that about 3 cents per kilowatt hour is pretty close to what can be done in an isolated plant to-day if the same consideration be given to the factors of the cost that I gave at that time. Personally I believe that an allowance of five per cent. for depreciation is insufficient.

While you can borrow money at five per cent. you can't borrow money at five per cent. on the ordinary isolated electric light plant, and if you are going to invest money in an electric lighting business as a speculation you would not be apt to invest your money when the maximum return possible would be five per cent., in view of the risk. My own opinion would be that 15 per cent. would not be at all too much to allow for the interest and depreciation charge on a modern isolated plant.

Another point which has always struck me as of very great importance and which is not sufficiently allowed for, is the value of the space that the plant necessarily occupies. While it may be true that in some instances plants will be found where there is no other use for the space, I don't think that is the rule by any means and I remember that without considering at all the question of space for a storage battery I have frequently been much puzzled to find room enough for the electric plant and it is very often a very serious problem. In the modern tall office buildings the space that the plant occupies in the basement is an important matter, and although the owner may not appreciate it fully, I consider that a continual charge should be made against the operating cost, for the maintenance of that plant in that space, because if he had not used the plant in that space he would have used something else there. So that it seems to me that with an allowance of ten per cent. only for interest and depreciation, and in disregarding entirely the value of the space occupied, the present paper leans too strongly in favor of the isolated plant. Of course, it is incontestable, at least I think so, that under favorable circumstances a large isolated plant can produce electricity at a price such that the central station company would have difficulty to compete with it, but I do believe that a great many isolated plants are being operated at a higher cost than the central station company could afford to take for the service. In some of the cases here quoted, even with this rather small allowance for interest and depreciation, and no allowance for the value of the space occupied, you will find 4.7, 4.3, 8.06, per K. W. hour, and figures of that character. I believe the central station would provide electric energy at those figures if they saw what the load was. These curves are particularly favorable as compared with the average curve of the central station, and the load factor being high, a low rate could be made for such service. I have always felt that there was quite a field in the direction of supplying energy from the central station at a flat rate per kilowatt for a 24-hour service, allowing the customer to have his own storage battery and thus purchase his power at the minimum rate. But as the author stated, there are many instances in which the economies which might be derived from a storage battery are not realizable because of the lack of space, and I also feel that a person who installs a storage battery in connection with an isolated plant necessarily adds or should add

almost a dollar a day to the value of the expert labor if he is going to keep his plant to the degree of minimum maintenance that he had before he put the storage battery in. And I personally think that the percentage allowance for depreciation, on the storage battery even to-day, is not such as compares favorably with that of a plant that has no battery.

It seems to me that the whole question boils down to the value of the heat of the exhaust steam as against the economy of production on a very large scale by a central station, over a small plant. Where the value of this heat is large the isolated plant would necessarily have an advantage. But certainly a central station plant should be able to, and I believe it does, produce a kilowatt hour at a very much lower rate than it could be produced by an isolated plant if we disregard the exhaust steam. Frequently figures of this character are largely a question of methods at arriving at results but there is every reason to expect that under skilled guidance a large central station should be able to produce energy at a rate such that nothing could compete with it except for this factor of the value of the heat for the exhaust steam. And since instances seem to be developing where the owner of an isolated plant finds that he can purchase from a central station, steam to operate an isolated plant, cheaper than he can operate his plant by himself, it would look as though in an average case the question of cost would be in favor of the central station, provided that the central station were able to sell its current for a twenty-four hour service and consequently sell it at a low rate. It seems to me that the central station ought to be willing, and I presume they are in some instances willing, to sell a steady load at about 3½ cents per hour for annual service, and I believe that energy bought at such rates and stored and used as required will compete quite favorably with the average isolated plant case.

But of course this question of elevators is a factor that nearly always is an important one, and the introduction of any means of equalization, such as a storage battery, would I believe operate elevators at an advantage as compared with the rates which would have to be charged by the central station if the current were so excessive at times, as the direct load of the average elevator demands, when operated by the ordinary methods in use to-day.

It seems to me that in this kind of a case the greatest saving can be effected by the owner making use of the service of a thoroughly competent and unbiased engineer, because each problem is one which must be studied by itself, and the various factors of electric light, heating, elevator service, etc., vary so widely that what in one case might result in a saving would in another case be a serious disadvantage.

MR. ARTHUR WILLIAMS:—Nothing, perhaps, could more clearly illustrate a point I wish to make in regard to the use of the exhaust steam of a private plant for heating than the curve which Mr. Moses has drawn—the characteristic load curve of an office

building. During the early part of the day, and in the early morning hours especially, the need for heat is at a maximum, whereas there is very little demand for artificial light in the late afternoon, when the demand for lighting, and therefore, the supply of exhaust steam is at a maximum; the necessity for heating is at a minimum.

Mr Moses' paper is based almost entirely upon conditions as he understands them in New York City, where he believes the possibilities of the near future for the central station are relegated to the supply of current for small customers and breakdown connections for isolated plants. The field of comparison selected is so local that I feel you will justify a reply, also local. I did not succeed in getting a copy of the paper until just before leaving New York Saturday and am not able, therefore, to make a statement in regard to each of the buildings to which it refers, but a number may be identified, and having been connected closely with that branch of the New York Edison company, I am able to show, to some extent, the side that has not here been presented. I learn in answer to a telegraphed inquiry, that of 118 large buildings erected in New York City in 1898, in the plans of which the isolated plant for both lighting and power was a factor, all but 22 decided to use the Edison service; of 66 such buildings erected in the first half of 1899, 60 have decided to use the Edison service.

There were several buildings in connection with which we submitted figures of cost, where in view of the low average use and the coincident local and system maxima, we felt that even at best prices the very large investment which the company would be compelled to make would leave us at the end of the year a considerable loser, and, while we desire to have it understood that our company is prepared to supply electricity in any building for any of the established uses, we did not regret the conclusions of the engineers and owners. It must be apparent, however, that in an instance where the company finds that its established rates subject it to loss, the conclusions of the engineer who encourages his principal to make very large and costly investments in generating and other electric machinery must be subject to serious question.

While attending the second electrical show in New York, an agent, in attempting to sell me an isolated plant, stated that the cost of operation was approximately half the cost of central station service supplied in New York. I said as central station service costs approximately one cent a 16-candle lamp hour, that of his plant would cost approximately one-half cent, to which he answered in the affirmative; I then asked him that if the central station service cost only one-half cent—an amount much in excess of the average price paid by the large buildings in New York—could the plant be operated at one-fourth cent. To this he made no reply, feeling, evidently, that he was getting into deep water.

The same motive that, in many instances, leads a consulting engineer to recommend the private plant actuates the operating engineer in keeping it in operation. An instance occured not long since in which the engineer of a large down-town building stated to the committee in charge, who were considering a proposition we had submitted to them, that he was making electricity at "one cent per K. W. hour or a little less," upon which statement, and without further investigation, the committee decided that it could not afford to substitute the local Edison service at five cents per kilowatt hour. It should be said that our own estimates, most carefully and, we believe, most accurately, prepared, showed a very large percentage of saving, with much greater satisfaction, in abandoning the plant.

Our experience with a large club taking central station supply, might be interesting: We were receiving approximately $8,000 a year from an installation of 1,200 lamps. The house committee felt that this was more than the club should pay, and authorized one of the prominent engineers of New York to prepare the necessary plans and specifications, upon which bids were obtained. These bids for the electrical and mechanical plant amounted to $35,000, to which the architects thought $10,000 should, or might, be added for the necessary building alterations. The engineer had stated to the committee that when installed, this plant would save enough each year to repay its cost in two or three years, after which the club would get its light for nothing, and this statement was repeated in all seriousness by one of the members of the committee at another meeting which I attended. It took little consideration on the part of the committee to find that far from saving anything by installing a plant they would in all probability increase their annual charges by as much more as they were then paying the Edison company; the fixed charges alone, including interest, depreciation, taxation, insurance, and "up-keep" expenses, amounted to very nearly 20 per cent. of the investment, or approximately $7,000 and they had been paying us only at the rate of $8,000 for everything.

One can hardly disagree with Mr. Leonard that the author's 10 per cent. is not enough for the fixed charges of a plant. Our New York practice is to include the interest value of the money invested at about 6 per cent.—it is worth much more when taken out of one's business—the depreciation at 8 per cent. allowing about twelve years' efficient life of the plant, taxes at 2 per cent. the actual rate being about 3 per cent. and 1½ per cent. for insurance, this item on steam and electrical machinery, being subject to variation. It will be seen that a very small addition for "up-keep" repairs, rent, accident insurance, or any of the other many items usually forgotten but still incidental to plant service, would bring the annual fixed cost to 20 per cent. of the first, or installation cost.

The statement of the writer, that the expense of operating a

private plant is the difference between the cost of the mechanical service of the building before and after its installation, should be qualified. And if the costs are given on the kilowatt basis, owing to the tendency to over-rate plant output, this statement or definition could become very misleading. The tendency, even in our own stations, where our people have no possible incentive, is to read the indicating instruments on the high rather than on the low side, and the average plant engineer, desiring to support and increase the importance of his position in every possible way, is certainly as cautious in this direction. In addition, the tendency of all consumers where not under the moral influence of the meter, is toward a very wasteful use of light or power.

Not long since, while the family were at dinner, we found three electric lights burning in the small parlor of an up-town apartment supplied by a private plant and the use of light in the halls and elsewhere seemed equally extravagant; and I recall an instance in which by placing a meter on an apartment where light was included in the rent, it was found that the cost of current used wastefully and for ornamental, in addition to the proper purposes, amounted to more than the landlord received from the tenant. It is safe to say that in either instance, and without reference to the source of supply. a meter would have cut down the use of current fully one-half, if not more—in fact in the second instance, when the tenant learned that the landlord had a meter on his circuit, though even then not paying directly for light, the consumption became about normal, which was less than one-fifth the previous consumption.

Another instance in our experience, showing that the tendency is to overstate private plant output, arose in connection with a large building for the supply of which the owner had asked our annual costs on the basis of the number of K.W. hours reported by his engineer. On finding that our first estimates greatly exceeded the cost of running the plant, we were led to make an investigation, which revealed the fact that the ampere meters were reading almost double the current generated, and that several items of expense properly charged to the generating plant had been charged to other parts of the building. The true figures of consumption showed that the central station supply offered a large saving, and the plant has since been idle. Many additional instances could be cited, showing conclusively that the K.W. consumption of a building is a very unsafe factor to determine the relative cost of central station vs. private plant supply.

For the large hotel of which Mr. Moses speaks, the Manhattan, of New York, the annual cost of electric light is placed at $13,000. These costs are estimated deductively by determining the difference in the cost of fuel and other supplies during a period in which the hotel was supplied with current from the local dynamos and for one in which the local Edison service—for lighting only—was used. It should be remembered that the building has ten or

twelve electric elevators, which, owing to the difference of voltage required, compelled operating the plant, notwithstanding our station supply of light during the entire period of the test.

That the sum given does not fairly represent the real cost of electric light is readily shown by the fact that the hotel last year consumed 6,000 tons of coal, costing $20,000, of which only 1,400 tons, costing $4,500, is allowed for light. Two thirds of the coal consumption, or 4,000 tons, it must be evident, are to be charged to both lighting and elevators; the elevators alone, therefore, if the statements made are accurate, would have consumed 2,600 tons, when certainly much the "smaller half" of the power generated was required for that purpose. The only fair test of this character would be to shut down the entire plant, supplying elevators and auxiliary motors, as well as lights, from the Edison service, crediting to that service in a comparative estimate the resultant saving that would be accomplished in labor, fuel, supplies, etc.; the space occupied could be utilized for other purposes and doubtless has a high rental value. The fact is that instead of costing $13,000 annually, the lighting of this building is probably costing more nearly $20,000, or, including the elevators, more nearly $30,000, whereas our estimate of Edison service for all purposes has never exceeded $25,000, and, under proper control, I doubt if the cost would reach that amount.

The apartment house mentioned by Mr. Moses offers another instance in which instead of showing a saving through plant operation we believe that there would be a very considerable advantage to the owners by adopting Edison service. I have no estimate of the present cost of running this building, but, taking another building, a hotel very much like it as to size, but where the conditious of service are much more onerous, the bills for the entire supply last year were something under $3,000. The proprietors recently considered the installation of a plant, but on investigation became satisfied that their existing service could not be replaced at a cost much below $6,000 annually, which agrees with the figures given by Mr. Moses. amounting to about $7,000 for the apartment house in question. Allowing a little more fairly for labor and taking a more conservative view of the investment value, even this high relative cost for the apartment house becomes nearly $10,000, undoubtedly a more accurate estimate.

The electric elevator supplied by meter is the cheapest service a central station can give The average cost of 15,000 H.P. supplied by our company last year was $18 per H.P. installed or approximately half the estimated cost of delivering coal at the doors of New York boilers. Only last week the proprietor of an apartment house found that his elevator service, continued through twenty-four hours daily, was costing approximately $3,800 per annum, whereas we have never supplied an elevator of that type at a cost exceeding $500, and the average is very much less. He

has abandoned the use of his plant, and is now arranging to substitute an electric for the hydraulic elevator. When the change is perfected the lighting and elevator service together will hardly amount to the former costs of the elevator alone.

On the basis of the estimate Mr. Moses has given, the electric light and power supply of the office building referred to on page 316 costs $7,000 per annum. It will be observed, however, that only 10 per cent of the installation cost, or $1,500 is allowed as covering interest, depreciation, and I presume, insurance, taxes and rental, though these items are not mentioned, while 20 per cent., as has been shown, is more nearly on a not too conservative basis, the proper charge, increasing in this one item, the estimated cost by $1,500. Another indication that the estimate is insufficient is found in the item allowed for lamps; $200 represents 1,000 incandescent lamps at 20 cents each, and as the reported consumption for the year was in excess of two million lamp hours, the average life of each lamp would be in excess of 2,000 hours. It is questionable whether any plant, using efficient lamps, where the standards of light are fairly maintained, secures a life of more than 600 hours. Either the item understates the cost of lamps, or the reported consumption of current is largely overstated.

Four hundred dollars has been allowed for "sundry supplies and ash cartage," an item which must include the water supply which last year cost more than $600, and the oil supply which amounted to more than 650 gallons; and according to the estimate presented to us, one man, receiving $18 weekly, runs this plant of four high-speed engines and dynamos, the necessary controlling and regulating apparatus and a storage battery. The estimate given, by fairly allowing for items mentioned, could easily be increased to $10,000, and it is extremely doubtful whether even this item represents the cost to which the proprietors of the building are subjected; on the other hand, I am certain that, supplied from our station at the usual rates, the cost for both lighting and elevator service would not exceed $7,500 per annum.

A storage battery is considered a medium of saving, and the cost of making the current, which I presume means its delivery at the switchboard or at the battery, as might be desired, is placed at 4.37 cents per K. W. hour. Our storage battery prices in New York start at 6 cents per K. W. hour, and descend on a graduating scale to 3 cents, a price with which I have yet to know of any isolated plant competing, operating charges alone, but fairly, considered. But even at 3 cents we have found it very difficult to convince anyone of the economy of the storage battery for which the central station supply is certainly more regular and better assured than that of a plant.

The writer's reference to the New York Wool Exchange, and its comparison with a large loft building, (page 322) brings out clearly the point I have made as to the wasteful tendency of engineers and tenants where current is supplied without direct

charge. The loft building with a plant consumed last year 100,000 K. W. hours, or 2,000,000 lamp hours; annually; the Exchange, having the same cubic contents, supplied through meter by the Edison company consumed only 822,000 lamp hours. The Exchange building has a comparatively high load factor while a loft building, such as that of which the author speaks, has the lowest load factor of any class we supply. As no complaint of an insufficient supply has been received from those in charge of the Exchange, we assume that they have had all the electric light and power required.

Allow me to draw your attention to the conclusion of the author regarding the Sohmer building of New York City. From his paper it is evident that the cost of electricity for lighting and power last year was $3,900, to supply which he now intends to install an isolated plant at a cost of $10,000, and expects to obtain current at about 4 cents a K. W. hour. The consumption for all purposes last year was 45,000 K. W. hours, which, at 4 cents, would cost $1,800. The fixed charges at 20% of the installation cost amount to $2,000, in addition to which it will be necessary to provide fuel, labor, incandescent lamps, engine room supplies, etc., as well as an auxilliary source of supply consisting of either gas or electric light service. Two men added to the labor force would at least add $1,500 to the fixed charges of $2,000, leaving a margin of $400 for coal and everything else required to replace the present service for the lighting and elevators.

The author's distinction between the practice of the speculative and the investment builder is to be taken, curiously, very much in the favor of the side he does not advocate. The speculative builder of New York erects the most substantial building that can be designed, usually with the expectation of filling it with tenants and of selling it at any time within two or three, or more years, basing his price at that time upon the investment value as determined by the net return which he is able to show as a result of the year's operation. It is an investment of the highest class, with every possible incentive on the side of the temporary owner to the highest economy—the far sighted economy. I do not remember at the moment of a single builder of that order who installed a plant last year; it was toward that class of builders that our first missionary efforts were directed, and their present practice is at extreme variance with that of three or four years ago, when for every such building a private plant was contemplated and usually installed.

Contrast this with a building erected by a permanent investor, in which a plant costing $35,000 was installed, to provide the electrical supply for about 6,000 incandescent lamps. The full service for both tenants and owner, who provided the public lighting, was supplied by the Edison company for something more than a year at an annual cost slightly under $6,000; 10 per

cent. of the investment cost, the amount which the writer of the paper thinks should be allowed for fixed charges, is $3,500 and 20 per cent, which we think should be allowed, is $7,000 or, in itself, more than all the charges of the Edison company. The plant has been recently started, and I understand that the single item of labor requires the addition of four or six employes in the engine and boiler room. In its operation it is expected to make money and supply current to the tenants at less than the amount of their payments of the last year to our company.

The central station requires machinery for about 30 per cent of its connected installation and finds this provision ample. The isolated plant, if properly installed, must provide from 100 per cent. to 150 per cent.; at the first figure, you have three times the machinery, installed under much more expensive conditions, upon which to base the fixed charges. Then consider the number of employes. Our company requires a man and a half to operate a 2,500 H. P. engine, while the 800 private plants of New York, aggregating probably only half our supplying capacity, will average at least three men to each. I think the entire city south of 10th street is operated through the night with a force not exceeding a half-dozen men, a number not greatly in excess of the force that would be required in one of the large buildings were night as well as day service supplied.

The author suggests that a discussion on the subject of gas engine plants would be interesting. I recall two instances of a number that have arisen in our experience. The first one is of a restaurant of considerable size, in which a gas engine and dynamo combined, of the latest type, were surreptitiously installed—I say surreptitiously, because the proprietor feared to communicate with us, thinking we would oppose his plans. We, however, learned of the matter before actual operation, and, on going over the contracts, found that the guarantees as to the consumption of gas, on a minimum basis, placed their cost alone at $3,500 (gas at $1.15 per thousand feet), whereas our Edison bills had amounted to only $2,700 for the preceding twelve months. The plant has never operated for more than a test run, and is one of a number which I think could be purchased at a very low figure.

The second instance is of a large hotel, in which the dynamos were operated by gas engines. Question having arisen, we installed Thomson meters on the dynamo leads and found that in a month, in which the gas meter showed a consumption of $206, the electrical meter at our published rates, recorded only $204. Nothwithstanding recent reductions in the price of gas, I think all of the gas engine plants in the district lines of the New York Edison company can be counted on the fingers of the hand.

That the superiority and relative cheapness of the Edison service is becoming more and more highly appreciated by engineers, architects and owners, is shown by the number of plants that are

abandoned, as well as by the relation existing between the plant and central station supply of the new large buildings, as indicated by the telegram I read a few moments ago. Several of the largest hotels in New York have plants idle in their cellars because of the saving in favor of Edison service, (and yet hotel service is the most difficult to compete with) and one of the largest down-town printing houses also abandoned its plant something more than a year ago, finding that the Edison service, which has never failed them, costs no more than the direct operating charges of the plant service, which gave a great deal of trouble. I speak of operating charges only, in each of these instances, as in the abandonment of a plant for competitive service, fixed charges of all character must be ignored, the investment having been made and the plant once installed possessing very little intrinsic value.

MR. STEINMETZ:—There is one reference in the paper recurring a number of times, regarding the fluctuating load imposed by electric elevators, and the hope is expressed that storage batteries may be used to equalize this load.

There may be some doubts whether storage batteries are advantageous in such isolated plants or not. They undoubtedly have been a very great success in large low tension direct current systems, but just as undoubtedly they have been an entire failure in street car propulsion and similar applications.

It is true that the elevator load is a severely fluctuating load. I doubt, however, whether in installing electric elevators due care has always been taken to make this load as little fluctuating as possible. There must always remain the fluctuation between the power consumption when running, and the absence of power consumption when standing still. It follows thus that the problem of the electric elevator in its relation to the power supply system is to make the power consumption as uniform as feasible during the time the elevator is running.

This means first that the starting current of the elevator should not be greater, but rather less than the running current. This can be accomplished by the use of a shunt motor of fairly low magnetic density with a powerful series coil which in starting remains in circuit until all the starting rheostat is cut out.

Second, to use power as uniformly as possible when running makes it obviously objectionable to use gravity for the descent, since thereby the power consumption during ascent is doubled. On the contrary, the car should be overbalanced for the average load of the elevator so that at the average load the motor supplies only the work of friction, more work when ascending with heavy or descending with light load, and less work in the opposite case. While this consideration really appears self-evident, yet I doubt whether it is always taken into consideration when installing electric elevators.

MR. MOSES:—Replying to Mr. Leonard, I wish to emphasize the point made in the paper, that the cost of electricity in a build-

ing plant is in no ways comparable to the cost in electric lighting plants out west. In an electric lighting plant, labor, coal, rent, taxes and insurance, are directly and solely chargeable to the electricity. In a building plant on the other hand, only the labor additional to that required for supplying other functions of buildings and only such coal as is additional to that required for the heating and for other apparatus (which can be equally well supplied by exhaust steam) are properly chargeable to the electricity. Rent, taxes, insurance, depreciation and interest charges are also quite different in building and in isolated plants. This brings me to the question of interest and depreciation charges. My figure of 10 per cent. has been strongly objected to. I still adhere to it for the following reasons: while I would not advise any client to invest his money in an electric plant unless more than 10 per cent. clear was assured, yet I consider five per cent. or even four per cent. as ample to allow for interest charge, as this is in excess of the actual amount an investor or owner of a building would pay for the money required to replace the capital invested in plant. As regards depreciation charge, I allow an average of 5 per cent. per annum (which with interest at five per cent. will equal original capital in fifteen years), for depreciation on the whole installation, which includes boilers, piping, pumps, engines, dynamos, foundations, alterations to existing building, boiler setting and alteration to wiring. This allowance is excepted to, on the ground that no plants last fifteen years. I can cite dozens of existing plants where boilers have been in daily operation for over twenty years, and are still allowed to carry from sixty to eighty pounds pressure, and many engine plants have been running for the same length of time. Direct current electrical machinery has only recently been standardized, and as electrical building plants are dependent on the existence of large buildings they are, of course, of comparatively recent growth.

Judging from the construction of the engine and of the dynamo, the latter should last at least thirty years with but little repairs. I am safe therefore, I think, in considering fifteen years as the average life of a plant. It has been objected, also that the continual changing of design should involve a larger depreciation charge. This I do not think will bear investigation.

The investor can continue to produce current from the plant he installed at the rates stated in the paper. If large improvements are made in machinery, he may find it worth while to completely change his plant. In this case, however, the cost of producing current will evidently be very much lower, so that, though his depreciation charge may have increased, his cost of operation will have decreased in greater proportion, as in any other event the change would not have been made. The rental value of the space occupied by the plant has been dwelt upon. Generally this value is not calculable, as the greater part of the space used is required for elevator, pumps and other machinery,

boilers and motors, and the space actually used by the electric plant is of no consequence. In some cases the added space is valuable, and must be taken into account. In general this is not so. Mr. Leonard states that the question depends on the comparative value of the heat obtained from exhaust steam vs. the increased efficiency of the large engines in the central stations. This is not the case. The value of the heat from the exhaust steam, while important, is not the deciding influence. A few of the reasons why the building plant can manufacture and deliver electricity cheaper than the central station, in addition to the benefits of use of exhaust steam for the heating, are that in the building plant little or no additional labor is necessitated by the addition of an electric plant, and such labor is always cheap. In the central station; labor for firing, for running engines, keeping books, collecting bills, inspecting outside and internal constructions testing meters, and selling current are direct charges on electricity. In the building plant there are no legal expenses, no treasurers or officials with large salaries, no increased insurance or taxes, no rent of subways (and generally no rent at all); besides which, interest and depreciation are reckoned on actual cost and only on the additional apparatus required for supplying electricity, and there are no patented distributing rights for which large sums are payable annually. In the central station all these items, which constitute more than two-thirds total cost are direct charges on the electrical current.

Mr. Williams intimates that because the Edison company installs generating apparatus and mains for but 30 per cent. of the total connected installation, that therefore, their investment is less, per unit of current delivered than in the isolated plant, where a capacity of from 100 to 150 per cent. total connected installation is installed. This is not the case. It is true that the capacity of the Edison stations is only 30 per cent. of the total connected installation, but the averge load is only one-seventh of this capacity. In this building plant, on the other hand, the average load is from one-half to one-quarter the total capacity installed. That is, the cost of the plant in the Edison stations for a given load is from two to three times the cost of the building plant. The fixed charges are at least twice those of the building plant. Replying to the criticisms on the use of the storage battery; the battery merely takes the fluctuating load, the integral of which is comparatively small. The allowance for loss in passage through the storage battery is about one-fifth of this and is not to be compared with the benefits derived from the steady load on the engine. Generally, however, its chief claim is based on the fact that it takes care of the night service.

With the storage battery in use on the Edison system the conditions are quite different, as in this case all the power and light are passed through the battery, and with the same percentage of loss the benefits from reduced rates are swallowed up in low

efficiency. Besides, the cost of a battery to take the whole load is very many times that of one to take the fluctuation of the load only.

Mr. Williams states in his discussion of the figures from a large hotel "that it must be evident that two thirds of the coal used in this hotel is chargeable to the electricity" and has evidently misunderstood my meaning in the paper. The "1400 tons of coal costing $4,500" are all that are actually chargeable to light and power not to light alone. To anyone familiar with hotel work it must be patent that heating the building, cooking and running laundry and ice machinery use more than half the steam required in the building, and it is this amount of steam or coal that I have called "the constant requirement" and which I have approximated by taking periods with nearly constant conditions of weather and service in which equal amounts of electricity were supplied. By subtracting the coal used in the first period from that in the second period a difference was obtained, which, as the electricity supplied in each case was the same, was roughly that required for the other uses enumerated above. This difference divided by the difference in the number of days in the two periods would give the "constant requirement" per day. His suggestion to throw the entire plant of lights and elevators on Edison circuit for a test was impracticable as the elevators are wound for 120 volts. Mr. Williams also criticises my figures on the office building and brings up a figure of $600 for water supply which he assigns to the plant. Most of this is used by the tenants through the building for other purposes, but I charge water to the plant at the rate of 25 cts. per ton of coal burned, which is the equivalent of 8 lbs of water evaporated per pound of coal, making due allowance for the fact that in winter the water evaporated is returned nearly wholly to the boiler and reused. The "lamp" and "oil" terms are taken from the records and it is not therefore necessary to discuss them.

In the hotel spoken of by Mr. Williams where the plant has been shut down for one year and three months, the owner has stated to me that he reckons the increased cost of the Edison service at about $100 a month. This is about the actual money increase over what it cost them when they ran their own plant, but as about $2500 was paid for current from an outside source at retail rates, the cost of operation of the plant (present cost $6660 a year) was about $3000. The plant installed was too small for the work and the breakdown connection was a necessity. The owner does not care to invest the necessary money now for putting in a proper sized plant, as the old hotel business is, to a certain extent, uncertain. In the Grand Union Hotel, where I installed a plant, and where no breakdown service is used, the cost of operation this year, excluding all saving due to decreased cost of gas, is over $5500 less than it was last year. One-half of this saving was due to the use of small coal, but the remainder is

the difference between the cost of electricity $4558 from the central station and the cost of electricity from the private plant. In reality, the saving effected was greater, as the hotel has increased its use of steam. The total cost of installation was $8000 and cost per K.W. hour, everything included 2.19 cents.

Mr. Williams refers to the moral influence of the meter and objects to my basing costs on the K.W. hour supplied. Where light and power are furnished free to the tenants the meter will have no moral effect. Where they pay for it themselves it has a decided effect. In one building of the same size as the Wool Exchange, cited in the paper, and with similiar conditions, current is sold to the tenants by meter at Edison rates and the profits pay the expenses of operating the whole building. In this building the cost per killowatt hour is five cents.

Mr. Williams criticises my statement that in the Sohmer Building current at four cents per killowatt hour can be produced. I have taken up the question of interest and depreciation charges already, and therefore deduct $1000 from his estimated annual cost, and the remaining $1,500 which he charges to labor and extra coal, may properly be divided in half, as the labor charge, is not increased in any way. The coal will be increased by about $500 per year and $250 is sufficient to allow for oil, waste and supplies. That gives a cost of $1,750 to which should be added cost of repairs, of lamps, ash cartage, boiler insurance, extra water and contingencies, not more that $500 or a total annual cost of $2,250.

The kilowatt hours supplied, as stated, are 5,000 for light and 30,000 for power, exclusive of the light used and paid for directly by the tenants of the first seven floors. I am perfectly safe therefore, in assuming that the total kilowatt hours supplied will exceed 60,000 which at four cents gives $2,400—that is $150 more than the total arrived at above, making all allowances for contingencies. Mr. Williams cites figures of comparative number of new buildings erected with and without plants and I, of course, presume them to be correct. Such general figures are extremely misleading as is shown in this instance, for it must be a matter of common knowledge that no large office building, properly so-called is erected without its own plant, unless the controlling officer of the erecting company happens to be also strongly interested in the lighting company. The speculative buildings were frequently erected without plants, but where the building is 50′x200′ or larger and 10 or more stories high this practice is antiquated and the owners of the buildings already up are rapidly installing plants. No large hotel is erected without a plant and the only large buildings that do continue to use street current are apartment houses, were light is paid for by the tenants directly and old houses where the owners do not feel warranted in spending more than is absolutely necessary.

If the present methods in building plants and in central stations

were those of five or three years ago, the answer as to the comparative value of the two services would be more difficult.

A few years ago all the trained engineers were employed by the central station or trolley companies, and every advantage of technical skill and large capital was on their side, while the building owner dependent on his stationary engineer fell rapidly behind in the march of improvement. Nowadays the owner of the large office, hotel or loft building has a first class progressive engineer in charge or employs a consulting engineer to keep a general control over the staff and operation. In some instances the complete plant is run for a fixed sum per year by a contractor who is able to make money himself and save the owner money as well, by purchasing large quantities of material at a time. This method while it renders many of the central station economies of both material and labor available to the isolated plant is only to be recommended when the contract is for such a length of time that the contractor will see that proper repairs and additions are made, whether he is momentarily financially the sufferer or not. It is these facts, that repairs are seldom made by the contractor until the plant breaks down, and that no improvements are possible on account of the short term of the contracts that have brought the system of contracting into serious disrepute. The same results can be obtained by placing the operation of a number of plants the purchase of their supplies and the employment of labor in the hands of a technical engineer, who should be paid a fixed sum per month by each owner. This will give the owner the benefit of the best engineering, improvements and all economies possible to large buyers, while at the same time the plant will not suffer through neglect of proper repairs.

Mr. Steinmetz:—In this paper, the depreciation is estimated on the basis of a 15 years life of the station. I like to ask the question whether any one of the gentlemen present knows of any station where apparatus and machinery installed 15 years ago are still in satisfactory operation. I need not ask the question whether you know of stations where apparatus installed less than five years ago has been thrown out as antiquated and unprofitable, since such stations are numerous.

Mr. Williams:—That question is answered by Mr. Moses himself where he refers on page 306 to the plant of the Manhattan Hotel as being even now "slightly old-fashioned." This plant was installed in either 1896 or 1897 under the supervision of one of the most competent engineers in New York. And would you allow me to say, correctively, of the Broadway hotel mentioned, that the books were carefully gone over, and there can be no question as to the figures which have been given.

Of the large office building, the point made was that the entire expense of lighting and power service supplied from the Edison station did not substantially exceed $5,000, while the fixed charges on the investment alone were fully $7,000, again omitting the

question of rent, which in that neighborhood is very considerable. In our discussion one side of the question has been entirely overlooked, the extent to which provision for a large mechanical plant increases the cost of constructing the building. In the Manhattan Hotel, I have not the slightest doubt, the necessity for providing for the engine and boiler-room in connection with the foundations and building structure, increased the cost fully $50,000, incidental to which there are fixed charges which must be considered in one way or another, an expense of the hotel.

The storage battery losses, as Mr. Moses says, are confined to but a percentage of the total output, but on the other hand this percentage must bear all fixed charges of the battery.

MR. C. W. RICE:—I am familiar with a plant that originally cost $50,000 four years ago. It is stationed underground, out under the sidewalk and they pay $250 a month rent. This plant costs about $17,500 a year to operate and I was authorized recently to offer to sell the plant. The prospective customer would not give $20,000 for the plant and operate it himself. He prefers to pay $17,500 a year and let others operate it.

[COMMUNICATED AFTER ADJOURNMENT BY MR. CHAS. BLIZARD.]

I desire to reply to Mr. Leonard's statements concerning storage batteries in isolated plants. I was not present at the Boston meeting and base my reply upon Mr. Leonard's remarks as reported.

Mr. Leonard expresses the opinion that the operation of a battery in an isolated plant does, or should, cause an increase in the cost of engine room labor. With the exception of the Edison companies and street railway companies operating batteries on a very extensive scale, and having two or more installations, I do not know of an instance in which the installation of a battery has added one dollar to the labor item. On the contrary, batteries in many cases have effected a very material reduction in the engine room force.

The modern storage battery in an isolated plant does not require the attention of a so-called expert, it needs only such intelligent care as can be given it readily by a competent engineer or his assistants. Seventy-five per cent of the plants in New York City are being operated with entire success by engineers who are now in charge of their first batteries. None of the more important electrical or steam apparatus in large isolated plants receives or requires so little of the engineer's time as the battery. It is safe to state that the time devoted to successfully operated batteries in isolated plants does not exceed an average of an hour per day per battery.

Instructions covering the proper care of a battery are simple and can be followed by any man who is competent to give intelligent care to a dynamo and engine.

Concerning the justice of charging against a battery a rental for the space it occupies, it has not been my experience that a battery is installed in a part of the building which could be rented. Many batteries have been installed recently in buildings which have been in service for a number of years, and the fact that spaces for the plants were found without the necessity of dispossessing tenants would seem to indicate that the portions of the buildings given over to the batteries were not available for rental purposes.

The depreciation of a properly constructed storage battery is a very small item. As renewals of the plates become necessary they may be made with plates of the most modern form and construction. The battery is thus kept in step with the latest improvements and never becomes out of date apparatus.

New York, August 7, 1899.

Associate Members Elected and Transferred at a meeting of the Executive Committee, held July 18th, 1899.

DIETERICH, FRED. G.	Solicitor of Patents and Mechanical Expert, 602 F Street, Washington, D. C.	J. McL. Murphy. Geo. T. Hanchett. E. V. Baillard.
SMITH, WM. LINCOLN	Instructor of Electrical Engineering, Mass. Inst. of Technology, Boston, Mass.; P. O. Box 415, Concord, Mass.	Louis Bell. Chas. R. Cross. H. V. Hayes.
SOWERS, DAVID W.	Assistant to Supt. of Power and Plant, The Yale & Towne Mfg. Co., Box 333, Stamford, Conn.	E. C. Boynton. H. E. Heath. R. W. Pope.

Associate Members Transferred to Full Membership.

Approved by Board of Examiners, May 12th, 1899.

F. E. SMITH,	Chief Electrician San Francisco Gas and Electric Co., 229 Stevenson St., San Francisco, Cal.
C. S. RENO,	Electrical Engineer, Triumph Electric Co., 620 Baymiller St., Cincinnati, Ohio.
A. ELLICOTT MACCOUN,	Superintendent of Electrical Department The Carnegie Steel Co., Braddock, Pa.
FRED'K. G. STRONG,	Box 959 Hartford, Conn.

A paper presented at the 16th General Meeting of the American Institute of Electrical Engineers, Boston, June 26th, 1899, President Kennelly in the Chair.

THE DETERMINATION OF THE WAVE FORM OF ALTERNATING CURRENTS WITHOUT A CONTACT MAKER.

BY HARRIS J. RYAN.

A method is given in this paper for determining the wave forms of alternating currents which uses no highly specialized measuring apparatus. No contact maker is used, and it is generally appliable on polyphase circuits only. It is recommended as a method which may be used under many circumstances where the special contact maker apparatus is not available.

Description of the Method.—In the diagram of FIG. 1, T is a special transformer with a closed magnetic circuit of soft, pure iron or "electrical steel" with the portion enveloped by the primary and secondary coils much restricted in area as compared with the remaining portion of the circuit. The circuit through each sheet is unbroken by joints, making it necessary to wind the secondary and primary by hand after the core forming the magnetic circuit has been built up. The primary coil is so proportioned that sufficient alternating current may be circulated in it to provide a maximum M. M. F. of about 500 C. G. S. per centimetre along the core at its restricted portion. Such exciting current may be taken from the secondary of an induction motor appropriated for the purpose, or from a set of phase changing transformers. Under these circumstances the flux through the core of this transformer will cause saturation during 97 per cent. of the time. The greater portion of the reversal of the flux will occur during 1.5 per cent. of the time of one alteration. The greater portion, therefore, of the secondary E.

M. F. time integral will occur during 1.5 per cent. of the time of one alternation and at the instant when the exciting current passes through zero. The remaining portion of the secondary time integral of the E. M. F. will be applied with symmetry throughout 98.5 per cent. of the alteration, being maximum on either side of zero for the exciting current, and gradually diminishing to zero during the time in which the exciting current is attaining its maximum value. It is seen then that the main portion of the secondary E. M. F. will be delivered with great suddenness at the time when the exciting current passes through zero.

In dealing with 40 cycles per second this E. M. F. will be delivered during 1.5 per cent. of the time of one alternation or in about 1/5000 of a second. It is seen also that the residue of the

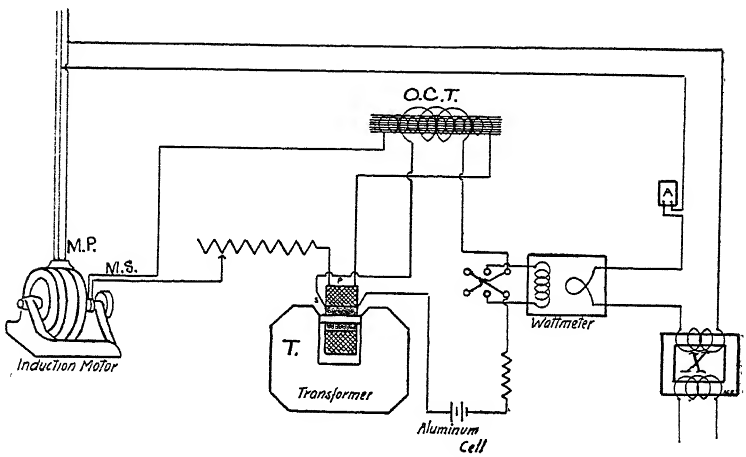


FIG. 1.

secondary E.M.F. constitutes an alternating pressure that is one-quarter cycle behind the primary exciting current. The cross-section of the restricted area of the magnetic circuit with reference to the amount of pressure applied in the primary circuit for excitation is proportioned so that the amount of irregularly delivered flux can not appreciably alter the exciting current, as it would otherwise be established from instant to instant.

The secondary of the transformer T is connected to the pressure circuit of a dynamometer—a Weston wattmeter does very well—through the field coil of which passes the current whose form is to be determined and which is set up by the source pressure through some appliance X. Let us call the sudden time integral

value of the secondary E. M. F. e, the instantaneous value of the current c, the effective value of the residue of the secondary E. M. F. E and the effective value of the current C, then the reading of the wattmeter will be:

$W = e\,c + E\,C \cos \theta$, where θ is the angle of phase difference between E and C, from which we may deduce the value of c. The phase of the exciting pressure delivered by M. S. may be changed by moving the motor secondary, or by a proper change in the value of the combined polyphase E. M. F.'s applied in the phase changing transformers, as the case may be, and a new instantaneous value of the current corresponding to the above

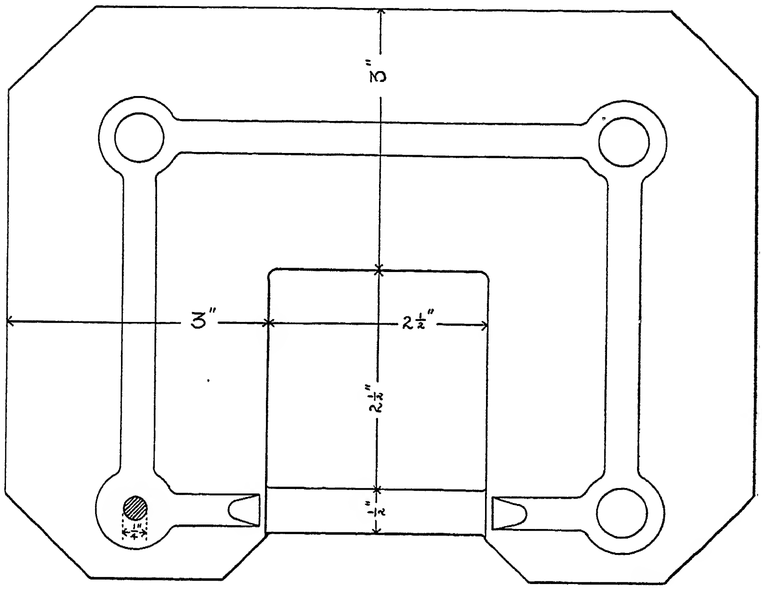


FIG. 2.

change in phase will be obtained. In the same manner other values of the current may be obtained until the form of the current curve is sufficiently well defined. To apply the correction $E\,C \cos \theta$ involves so much attention and labor, as to make this method valueless if it were not for the fact that it can be quite completely compensated for in the following manner: The exciting current through the primary of the transformer T is passed through the primary of a suitably designed open circuit transformer O C T, and through the secondary of O C T the connection of the impulse secondary from T is made on its way to

the wattmeter. The E. M. F. developed in the secondary of O C T will be one quarter cycle behind the primary exciting current of the impulse transformer T and therefore in unison with the residue E. M. F. of the impulse secondary of T. The secondary turns on O C T are adjusted in number so that the E. M. F. generated will equal the residue E. M. F. of the secondary of the impulse transformer T, so that when the connection through the secondary coil of O C T is reversed the residue E. M. F. of the T secondary will have been compensated for.

The reading of the wattmeter will then become $W = c\,e$, and

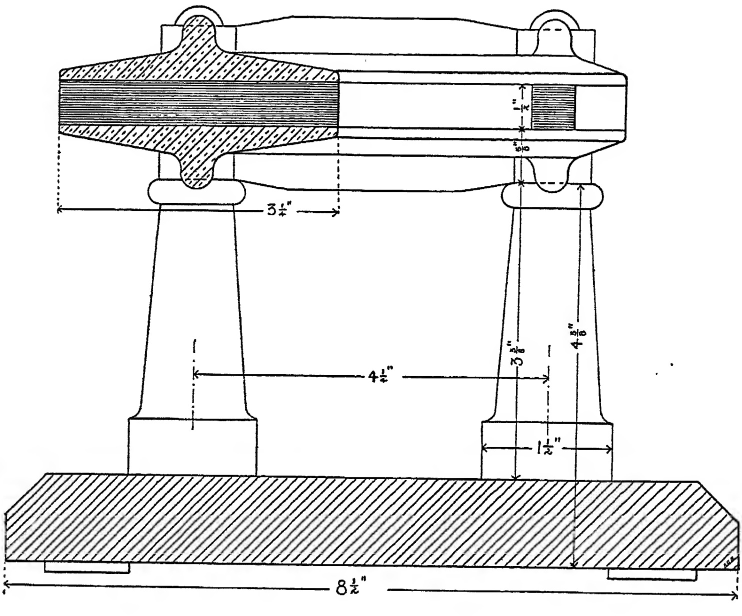


FIG. 3.

since e is constant, the values of W will be proportional to c or the instantaneous values of the current.

By using a dynamometer voltmeter, such as the Weston type, in which separate terminals for the movable pressure coil and field circuits have been arranged, the forms of alternating pressures and of tiny alternating currents may also be determined.

Thus this method is practicable only for instances where the plus and minus alternations are alike, which is the case in much alternate current practice. Where, however, the positive and negative forms differ, one or more aluminium cells should be

placed in series with the impulse secondary. Such cells have small internal resistance and after having been charged with a direct current will completely cut off one side of the alternating impulse, provided the instantaneous pressure in the circuit at no time exceeds 20 volts per cell. Thus equipped the method may be used with Weston or similar make of instruments for form measurements in great variety and with ease and facility. This method is practically the same as Dr. Duncan's[1] except for the manner in which cyclic impulses are obtained.

A Trial of the Method.

At my suggestion a trial of this method was made by Mr. Lyman H. Brown during the spring of 1898 in the laboratories at Cornell.[2]

Design and Construction of the Impulse Transformer.—Figs. 2 and 3 give a plan and elevation of the transformer as constructed and used by Mr. Brown. The following are the important dimensions and specifications: The core was built up without joints from 10 mil Apollo "electrical sheets," from which the burr due to shaping was carefully removed. The oxide on the sheets afforded the only insulation against eddies. The frame for bolting the core together was of brass, and did not extend over the restricted section of the core. The bolts were thoroughly insulated from the core and brass frame. The supports and base were made of oak.

No. of turns in primary	547
Size of primary	14 B. & S. G.
No. of secondary turns adjustable	.
No. of sheets	48
Thickness of a sheet	.01 in.
Area of contracted cross-section of core,	.25 sq. in.
Area of un-contracted cross-section of core,	1.5 sq. in.
Length of contracted section,	2.5 in.
Total length of magnetic circuit,	10 in.
Normal primary exciting current,	3 amperes.

On the assumption that a sufficient phase changing pressure is applied in the circuit, through the primary of this impulse transformer, so that the irregularities in the flux set up in the core will not appreciably alter the form of the exciting current, and with the aid of a B-H curve for the Apollo iron, I have

1. Transactions, vol. ix, p. 179.
2. Thesis, Lyman H. Brown, Cornell University Library, T-1898, No. 30.

calculated the following sequence of E. M. F's. that will be set up per turn throughout one quarter cycle in the secondary of this impulse transformer, when working at 40 cycles per second. The fractions in the time column give the portion of a quarter cycle that has lapsed since the exciting current passed through zero; the figures under B show the flux density in lines per sq. cm. in the contracted section of the core, and the values under E in the brackets, showing the time interval over which they were estimated, give the average of the E. M. F's. developed per volt in the impulse secondary.

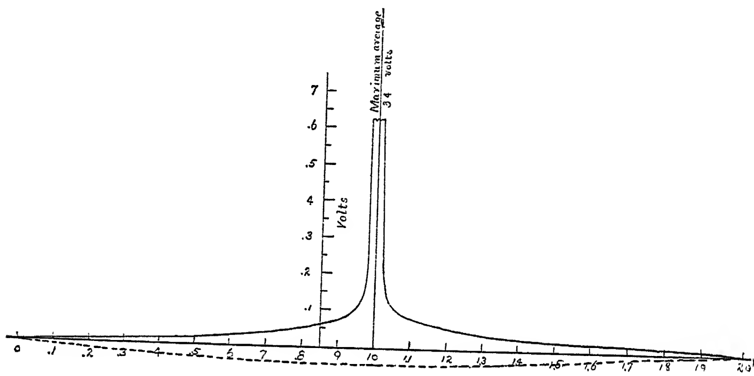


FIG. 4.

Time	B	E
0.00	0	3.24
.01	12,500	
.02	14,900	.623
.03	15,800	.1065
.04	16,400	
.05	16,800	
.06	17,200	
.07	17,400	
.08	17,700	
.09	18,000	
.10	18,200	.0644
.20	19,200	
.30	19,800	.0258
.40	20,300	
.50	20,800	
.60	21,150	.00644
.70	21,400	
.80	21,450	
.90	21,500	
1.00	21,550	

The corresponding impulse curve of E. M. F. and time, is given in Fig. 4 for a complete alternation. The broken curve shows the estimated compensating E. M. F. that should be provided by the secondary of the transformer O C T in Fig. 1.

Experimental trial made by Mr. Brown:—A compensating open coil transformer was used that had the following dimensions:—

Core of laminated iron, ring pattern	
Mean diameter of ring	8.75″
Cross-section,	$1\frac{7}{8}'' \times 2\frac{1}{2}''$
Air gap	$\frac{5}{16}''$
No. of primary turns of No. 10 B. & S. G.,	121
No. of secondary turns adjustable,	

A 150-watt scale Weston wattmeter, wound for 150 volts and two amperes, was used as a dynamometer; the resistance of the pressure coil was cut down to a point where the instrument operated over a desirable range. Ten secondary turns were placed on the impulse transformer, T, and the same number was found necessary for compensation on the O C T transformer.

At X in Fig. 1, the secondary of the 10-light transformer

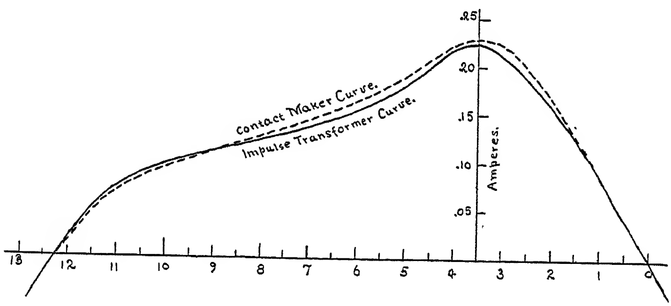


FIG. 5.

reported upon in the TRANSACTIONS, vol. vii, p. 1., was connected through the field coil of the wattmeter, to one pressure of the triphase source. The primary was kept on open circuit. By means of an auto-converter, the source pressure was so adjusted that a normal flux was established in the core of the 10-light transformer, X. For a phase changer, a Siemens and Halske 3 H. P., 33-cycle, triphase, 4-pole, 110-volt induction motor with a ratio of transformation of approximately one, was used. By means of an index wheel and brake attached to the motor pulley, the motor secondary could be set to develop any desired phase for the exciting current of the impulse transformer. The phase changing pressure was set at 100 volts, and the current controlled partly by reactance, and adjusted to the desired value of approximately three amperes, by means of a

non-induction resistance. A complete reactance control and a higher phase changing source pressure would, however, have been better.

In Fig. 5, the unbroken curve is an alternation of the magnetizing current for the transformer at x, as obtained by Mr. Brown in the employment of this method, while the curve is the mean of the two alternations for the one given in TRANSACTIONS, vol. vii, p. 12, as obtained by the contact-maker therein employed. The three-phase generator which supplied current for the experiments, had its armature conductors distributed on a smooth core, and developed at no load a fair approximation to a sine curve of pressure. The full load current output of this generator was 20 amperes, while the induction motor used for phase changing, required 10 amperes for field excitation. The armature reaction produced by this exciting current, was comparatively large, causing the generated pressure curve to differ some from the pressure curve used at the time the original contact-maker measurements were made.

There is, therefore, a fair practical agreement between the curve taken with the polyphase impulse transformer method, and the curve taken with the contact maker. It was found by Mr. Brown that 10 impulse-residue E. M. F. conpensating turns were necessary, while my estimates showed that but five should have been necessary. This difference is probably due to the fact that the sheets were not annealed after they had been tooled into shape, and that complete reactance control of the exciting current for the impulse transformer was not used.

No experiments have been made in which the aluminium cell was used to cut out either the plus or minus impulses so that the forms of unsymmetrical curves could be determined. Experimental data have been obtained by H. J. Hotchkiss[1], from which it is seen that the aluminium cell will be found to be reliable for this purpose.

Department of Electrical Engineering,
Sibley College, Cornell University.
June, 1899.

1. *Physical Review*, March, 1899.

ADDENDUM

[COMMUNICATED AFTER ADJOURNMENT BY HARRIS J. RYAN AND E. F. SCATTERGOOD.]

Since the date at which this paper was read we have made with the aid of a carefully adjusted contact-maker a study of the impulse transformer, the method employed for compensating the impulse residue E. M. F. and the use of the aluminium cell to cut out alternate impulses.

We have found that the transformer employed in the trial made by Mr. Brown is not proportioned so as to give the best results. The saturated portion of the core is too long, the iron sheets are too thick and it is desirable to shorten the length of the induction path through the unsaturated portion of the core as much as possible. To avoid eddy currents as much as practicable, better insulation between the iron plates should be used than that provided in the transformer made by Mr. Brown under the direction of the author of this paper.

We have found that induction reactance, ($L\,\omega$), with the minimum resistance possessed necessarily by the circuit, should be used to control the current in the primary of the impulse transformer. Excellent results as will be seen below when the transformer is well constructed, are obtained by impressing upon the primary circuit an effective pressure that is double the maximum impulse volts which are to be delivered in the secondary where the ratio of transformation is one to one. A higher pressure would slightly elevate the impulse E. M. F. and improve it in form without changing its time integral. A lower pressure should not be used. In all cases the primary exciting current should be large enough to give the restricted portion of the core a maximum M. M. F. of 500 to 600 ampere-turns per .393 inches of length.

Below are given the specifications for an impulse transformer that we constructed to use in connection with our Weston or Thomson wattmeters. For small currents up to .05 ampere we have used the ordinary Weston alternating voltmeter, having separated its field and moving coil circuits and having drawn a watt scale underneath the voltmeter scale. Such a watt scale is quickly calculated from the voltmeter scale and the resistance of the instrument.

Number of sheets in core	100.
Thickness of each sheet............	.006 in.

Length of saturated portion of core	.395 in.
Average length of unsaturated portion of core	7. in.
Ratio of width of saturated to unsaturated portion of core	8.9
Number of primary turns	20.
Size of primary conductor, B. & S. G.,	12.
Number of secondary turns	20.
Size of secondary conductor, B. & S. G.,	24.

Additional Specifications :—

Each core sheet was cut from photographer's ferrotype plate. This material was selected for the core because we could not wait for the arrival of thin Apollo "electrical steel" or material of equal grade. The ferrotype sheets, as is well known, are enameled making it unnecessary to provide further insulation to break up eddies. Each core sheet was cut to the following dimensions :

Size of sheet	4.5 x 5. in.
Thickness of iron	.006 in.
Thickness of sheet including enamel	.015 in.

Two openings to provide space for the primary and secondary coils were cut at the center of each sheet allowing a tongue, the saturated portion, to stand.

Length of tongue	.393 in.
Width	.4 in.
Size of each of these openings, length	.393 in.
width	.6 in.

The transformer was immersed in oil so that the primary coil would not become too warm.

The induction path in each sheet was continuous. Joints were not used to facilitate winding ; they would interfere with the desirable properties of the induction circuit. The primary and secondary coils were wound into position by poking each turn through the openings provided in the core.

In the above design we wished to make the average length of the unsaturated portion of the core quite as short as is practicable in an actual construction. From the performance of this and other impulse transformers that we have constructed and tested, we have found that the openings through the plates to accommodate the primary and secondary coils may be made broad enough to permit of the use of sufficient copper required to avoid undue heating when the transformer is operated in the open air.

The most available length of saturated core for use with Weston and Thomson instruments of the dynamometer type appears to be about .4 inch.

At 33.5 cycles this transformer gave an open circuit secondary impulse E. M. F. as follows:

Maximum value of impulse E. M. F., volts	24.
Width of impulse at top in per cent. of one half cycle	1.67 %
Width, one volt from base of impulse E. M. F.	5.55 %
Width, average of impulse E. M. F.	3.66 %

At 100 cycles the impulse E.M.F. had the following dimensions:

Maximum value, volts....	56.4
Width. average, in per cent. of one half cycle	4.4 %

The forms of a number of impulse E.M.F.s were taken with the impulse secondary on open circuit and then closed through 50 non-inductive ohms and at other times through the moving coil of a Weston alternating voltmeter which had a resistance of 45 ohms, to determine the effect upon the form of the impulse E.M.F. caused by the draught of about that much impulse current which is drawn in making instantaneous measurements. The effect of the draught of this current was noticed in all cases. It lowered the impulse E. M. F. maximum by approximately one tenth, and increased the average width about the same amount.

Under all circumstances this transformer is used with a primary exciting current of 20 effective amperes. In series with the primary is inserted a self-induction of .0095 henry. Forty effective volts are, therefore, required for primary excitation at 33.5 cycles and 120 volts at 100 cycles.

The following method for determining the number of compensating turns to be used as described in the paper in connection with O. C. T. in Fig. 1 was found to be entirely reliable. These opposing secondary turns at O. C. T. are adjusted in number by trial so that the wattmeter in Fig. 1 reads one-third less with compensating turns than it does without them.

We have made a sufficient examination of the properties of the aluminium cell to determine the conditions that regulate its use for the purpose suggested in this paper. Carbon-aluminium cells were used with a solution of a trace of sulphuric acid in water almost saturated with alum. Where small aluminium electrodes were used, we found that the cells would form themselves, operate continuously and cut out alternate impulses. At 33.5 cycles with impulse E.M.F s generated as specified above, and aluminium electrodes varying from .0767 to 2.41 sq. in. in series with 50 ohms, the cells rectified continuously. These phenomena of rectification were examined critically with the aid of the contact maker. In all respects the actions witnessed were precisely the same in character as those recorded by H. J. Hotchkiss[1] with his remarkable oscillograph in the process of rectifying an alternating current of ordinary form at the low periodicity of 17 cycles. The small

1. Physical Review, March 1899, reprinted in the *Electrical World and Engineer*, July 22, 1899.

capacity current there witnessed becomes increased with the periodicity. The impulse E. M. F.s have the character of a very high frequency alternating pressure in relation to capacity. The above impulse E. M. F.s produced at 33.5 cycles have characteristics for capacity phenomena that correspond to a periodicity of 800 cycles. It follows then that had Mr. Hotchkiss made his oscillograph records, supposing that to be possible, at 800 cycles instead of at 17 the capacity current seen in his records as superimposed upon the rectified current phenomena would have been increased 47 times. This will make clear then why we found the large capacity effects as given below.

In all cases where the small aluminium electrodes as specified above were used, the rectifying phenomenon was complete and definite. In every case the superimposed capacity current referred to above was witnessed. The smaller the aluminium electrode the smaller was the capacity current and the greater was the resistance of the cell, however close the electrode was placed to the carbon rod electrode.

The following dimensions of the impulse E. M. F. and capacity phenomena pressures were observed around the terminals of a 50-ohm non-inductive resistance in series with the impulse secondary and one aluminium cell as specified. The impulse transformer was operated at 33.5 cycles and excited with 20 amperes at 40 volts delivering the impulse E. M. F. in the secondary as described above.

DIMENSION OF		Aluminium Cells.		
		A	B	C
Surface of electrode in square inches		2.41	.512	.0767
Surface of carbon electrode in square inches		3.75	3.75	3.75
Distance between electrodes in inches		.5	.5	.5
Impulse E. M. F. left standing by aluminium cell.	Maximum positive volts of impulse	16.3	14.2	9.
	Average width of same in per cent. of one-half cycle	3.5	3.5	3.
	Maximum volts negative, caused by capacity effect	2.	.8	.1
	Average width of same in per cent. of one-half cycle	5.5	1.5	1.5
Capacity E. M. F. caused by cell where impulse E. M. F. was cut out.	Maximum volts positive capacity effect	10.3	5.2	.8
	Average width of same in per cent. of one-half cycle	6.7	1.5	2.2
	Maximum volts of negative capacity effect	10.8	4.2	.4
	Average width of same in per cent. of one-half cycle	3.33	1.	1.

It appears from this table that trustworthy results can be ob-

tained when using this cell, only by applying the smallest practicable aluminium electrode. With larger electrodes the capacity currents will introduce errors in the instantaneous measurements of wave forms especially in the neighborhood of their zero values.

Cells as constructed above but in which larger electrodes are provided, were found to be entirely useless for this purpose.

When using this method for measuring the wave forms of capacity currents involved largely in the production of the "corona" effect where the + and — alterations differ in form, we found that a commutator for cutting out every other impulse attached to Prof. G. S. Moler's cycle counter worked so satisfactorily that we preferred it to the aluminium cell. The aluminium cell with a small electrode is so easily made when one does not have at hand a cycle counter, that it will doubtless be found convenient and useful in many cases where measurements are to be made to determine the separate forms of the + and — alterations.

Discussion.

Mr. Steinmetz:—I have listened with great interest to Prof. Ryan's paper giving a novel and very ingenious method of wave shape determination. I consider this as one of those elegant, and I may say artistic solutions of a problem which are of considerable interest by themselves, even outside of the problems they deal with.

Regarding the contact maker, however, there is the disadvantage that no contact maker can really give the points of the curve, but necessarily gives a certain range, since even if an instantaneous contact can be made, which is not possible, the arc following the contact for an appreciable time prolongs it. We must consider that at a frequency of 125 cycles, a contact of .0001 of a second represents over four degrees of phase and thus will blur and smooth out very high harmonics as they occasionally occur.

The only method which I found to give really instantaneous readings, that is points of the alternating wave and not averages of a short range, is the method devised some years ago by Mr. F. Holden, and in continuous use since that time in our factories.

The contact maker disk consists of two segments per pole and is driven either by the alternator, or by a small synchronous motor. One of the segments establishes connection between the alternator wave and a condenser, the other section closes the condenser through a voltmeter or other instrument. As seen, in the moment where the condenser disconnects from the alternating wave, its charge is proportional to the alternating potential at this very point, but no current flows except the differential of current cor-

responding to the change of charge of the condenser, and no minute arc prolongs the contact. Thus the instrument reading of the discharge current of the condenser is directly proportional to the potential of the alternating wave at the very instant where the condenser disconnects from the alternator.

DR. SHELDON:—Concerning the aluminium cell mentioned in the paper, the inference is to be drawn that there is a high electromotive force of polarization. A few experiments which I have made indicate that there is no polarization of the magnitude frequently mentioned. Instead, the opposition to a flow of current is really due to a formation of some aluminium salt on the electrode. This salt is a non-conductor, and upon reversing the current it is carried back into solution. These conclusions I have drawn from the fact that an aluminium electrode becomes quickly heated, with a very small current, showing that the considerable number of volts lost right at the surface of the plate are used in overcoming resistance with the resulting heat development rather than in producing chemical decomposition.

MR. STEINMETZ:—I had occasion lately to investigate this feature somewhat further and was struck with the almost absolute arrest of current by the aluminium cell, a potential of 15 volts sending no noticeable current through a single cell from aluminium to carbon, while from carbon to aluminium the cell acts practically as short circuit.

I have investigated the cause of this phenomenon, and believe it is due to a thin film of aluminium oxide forming at the surface of the aluminium plate, as soon as current begins to flow therefrom into the electrolyte. This film being a good insulator practically interrupts the circuit. Experience has shown me that the phenomenon occurs only with such electrolytes as do not react electro-chemically upon aluminium oxide. The efficiency of this electrolytic rectification is very small, but considerable differences exist between different electrolytes. An investigation in this direction is still in progress.

PROF. C. A. ADAMS:—It is my experience that too little stress is ordinarily laid upon the duration of contact in the more familiar contact-maker methods. The machines used for such work in many college laboratories are of the bipolar type, in which the mechanical arc of contact and the electrical arc of contact are the same, and it is therefore not difficult to reduce the mechanical arc to such a point that the variation of E. M. F. or current during the interval of contact, is a very small percentage of the maximum; but when this same contact maker is applied to the shaft of a multipolar alternator, the electrical arc of contact is multiplied by the number of pairs of poles, or by the number of cycles per revolution, and it becomes very difficult to reduce the time of contact to the point necessary for accuracy, if the ordinary type of contact maker is used. Some years ago I devised a contact maker which practically does away with this difficulty and which has been in

successful use in our laboratory ever since. It is ordinarily used in connection with the well-known telephone method, and is illustrated in Fig. 6. Once during each revolution, the hardened steel pin, P, makes contact with the steel spring S, and thus closes the contact maker circuit through the stiff strip B, but almost simultaneously with this closing the circuit is opened by the separation of S and B. Thus the same blow that closes the circuit opens it, and almost simultaneously. The duration of the contact is so small as to be negligible, even with high periodicities, perfect silence having been obtained in a very sensitive telephone, with an alternator of 180 cycles per second.

PROF. RYAN:—I would like to add a word to the very interest-

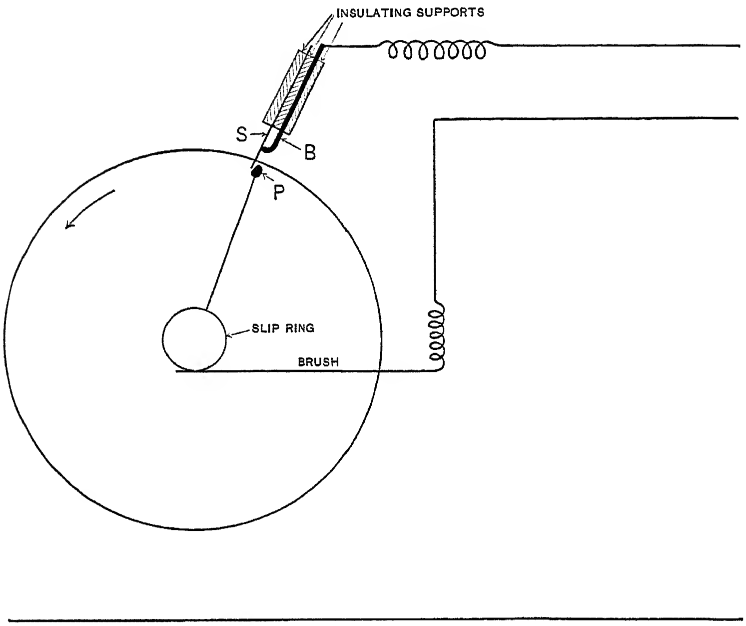
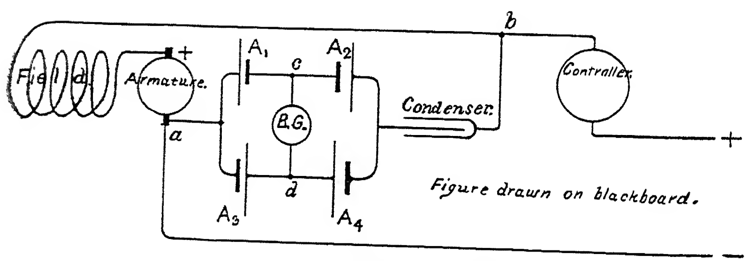


FIG. 6.

ing and beautiful method that Mr. Steinmetz has described,—to mention just now a use of the condenser a little different from that of tracing the forms of alternating values. Very often one wants to know just what the maximum pressure is that the insulation of a machine is strained to in practical operation. For instance in a street car motor it is of value to have a method by which we can tell what the highest electro-motive force is that the motor is capable of producing when the current is thrown off by means of the controller. If you use the condenser in series across the terminals of the motor *a b* and then through a battery of aluminium cells in this way: [See Fig. 7.]

This arrangement of the cells comes to us from our German friends. Across here we put a galvanometer, *c d*; the condenser of course will be given a definite charge due to the maximum pressure the system is subjected to, and the condenser will discharge itself. The charge will come through the galvanometer in a certain direction in charging up, and it will discharge in the same direction by virtue of the action of those cells, so that you have a throw on the galvanometer that is proportional to the maximum electromotive force developed in manipulating the motor.

PROF. C. P. MATTHEWS:—Professor Ryan has referred to the admirable little galvanometer perfected by Mr. Hotchkiss. I think this little instrument and its possibilities are not sufficiently familiar to the electrical engineers of this country, and this fact leads



A_1, A_2, A_3, A_4 Aluminium Cells.
B.G. Ballistic Galvanometer.

FIG. 7.

me to speak of it at this time. It is a galvanometer of almost microscopic dimensions, constructed along lines suggested by the oscillograph of Blondel. The natural period of the suspension is so exceedingly small that the needle follows with great accuracy all the irregularities in the wave form, and one obtains on the photographic plate a trace which shows the conditions obtaining at a given instant. These advantages are secured, it is true, at a cost of considerable skill and patience in preliminary arrangements, but the results are very gratifying, and I should be glad to see the apparatus in more common use.

PROF. RYAN:—The remarkable apparatus of Mr. Hotchkiss corroborates the experiments made by Mr. Steinmetz with the aluminium cells.

[Adjourned to Tuesday, June 27.]

A paper presented at the Sixteenth General Meeting of the American Institute of Electrical Engineers, Boston, June 27th, 1899, President Kennelly in the Chair.

ELEMENTS OF DESIGN FAVORABLE TO SPEED REGULATION IN PLANTS DRIVEN BY WATER POWER.

BY ALLAN V. GARRATT.

In this paper the writer will endeavor to describe those peculiarities of design of plant which have a special bearing on speed regulation, but no attempt will be made to discuss the theory, mechanical construction or merits of the various water-wheel governors on the market.

The engineer is often confronted with the problem of designing a plant upon an undeveloped or partly developed water power, and the desired end is to come out with a plant of good mechanical and electrical design and yet have it such that the speed of the electrical apparatus may be maintained within comparatively close limits under any load variations which can possibly occur, and to maintain the speed within very close limits under any working load variations.

The kind of generating apparatus used, and the nature of the load, predetermines the degree of regulation which must be obtained under both accidental and working conditions, but it is quite evident that the tendency in modern plants is in the direction of apparatus which requires closer speed regulation, and more facility in handling the speed than heretofore.

It is quite possible to obtain on the market, water-wheel governors which will,—provided the design of plant is good,—give quite as good a speed regulation as could be obtained if the plant were driven by first class steam engines.

There is more than one water-driven electric plant in this country where auxiliary steam plants are used, in which the speed is fully as constant while the load is carried by the water-wheels as while it is carried by the steam plant. The plants of the Derby Gas Co., the Pawtucket Electric Co. and the Woonsocket Electric Co. may be referred to as examples illustrating the above fact.

The largest accidental load variation which can occur is evidently an instantaneous change amounting to the full capacity of the water-wheels. The working load variations may be anything less than this.

The writer has found, in a practice amounting to something over 90,000 horse power of water-wheels in the last four years, that with good water-wheels properly set and rigged, and controlled by governors of suitable design, the speed may be held within five or six per cent. of normal upon circuit breakers opening under full load, and that the speed may be brought back to normal in from five to fifteen seconds, depending upon the amount of kinetic energy in the rotative parts and moving water column. With incandescent loads of the ordinary type, a recording tachometer will show a practically straight line. With ordinary electric railway loads, speed variations of about three per cent. as a maximum may be expected. These figures are not intended to be of universal application, but are for simply showing the present state of the art. It should here be added that governors can be obtained which will permit any number of independent water-wheel units driving electrical units connected in parallel, to be operated with perfect convenience and safety. It should also be noted that in the case of alternating units it is perfectly easy to get them at speed and in step for multiple connection without undue delay, and without any hand regulation.

These desirable ends cannot, however, be obtained to their fullest extent if the general design of the hydraulic portion of the plant is bad. We will now consider those things, aside from the governor itself, which tend to make the regulation good or bad.

As a preliminary thought let us consider for a moment that the problem is quite different from steam-engine governing, which naturally comes to the mind in this connection, for the reason that water is heavy, practically non-compressible or non-expansive, and must be transmitted to the water-wheel in large

volume and at low velocity; while steam is light, highly compressible and expansive, and may be transmitted to the engine in small volume and at high velocity. From this it follows that the engine valves are small, light and may be perfectly balanced, while water-wheel gates are necessarily large, heavy and are frequently,—although often unnecessarily,—out of balance. The inertia of the steam may be always neglected; the inertia of the water must be always considered.

The problem of governing a water-wheel, then, involves moving large volumes of a heavy, practically incompressible fluid acted on by the force of gravity alone, and of moving ponderous gates; and this must be done with absolute precision and great promptness. Also adequate provision must be made for the momentum and inertia of the moving water and mechanical parts.

To put our minds in a proper attitude to approach this subject, let us refresh our memories in regard to some of the relations of force, mass, velocity and time.

We have here a mass free to move. Its property of inertia prevents its moving until some force is applied to it. When, however, I apply for a moment the force of my hand it begins to move, and when I stop pushing it, it continues to move with a fixed velocity until I apply to it the same amount of force I used to put it in motion which brings it to a rest, and it cannot move again until a new force is applied to it.

I have here a pendulum beating seconds, and here, (Fig. 1) are two masses consisting of pairs of balanced weights suspended by fine wires over pulleys which have as little friction as possible. One of these masses is twice as great as the other. If we apply to them equal forces in the shape of small additional weights we will find that at the end of one second the smaller mass has acquired twice the velocity of the larger mass; or, in other words, where forces are equal the rates of acceleration are inversely proportional to the masses.

But now I have here two equal masses (Fig. 2) and if we apply to them two forces,—one twice as great as the other,—we will observe that at the end of one second, the velocity of the mass acted upon by the larger force is twice as great as that of the mass acted upon by the smaller force; or, in other words, where masses are equal, the velocities are proportional to the forces.

Now, I have here two masses, (Fig. 3) one twice as great as the other, and if we apply to the larger mass a force twice as great as that which we apply to the smaller mass, we will observe that at the end of one second, their velocities are the same; or, in other words, for equal velocities, the forces must be proportional to the masses.

Or, to generalize; velocities are inversely proportional to masses, and directly proportional to forces.

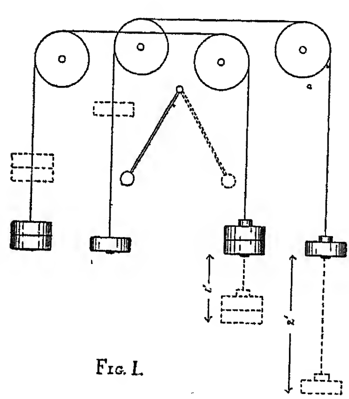


Fig. 1.

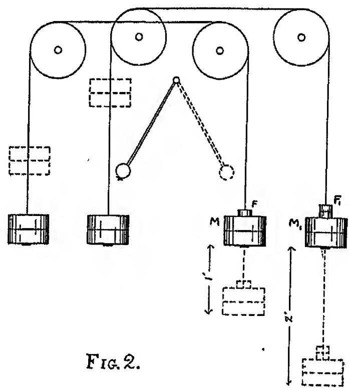


Fig. 2.

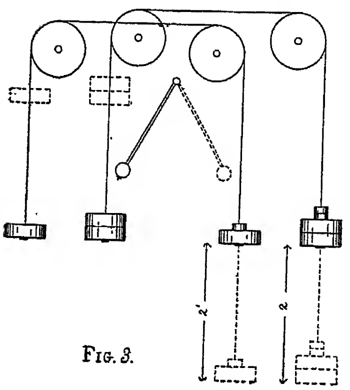


Fig. 3.

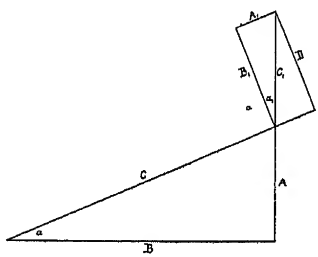


Fig. 5.

Or, by assuming the unit of force as that force which will, in unit time, give unit mass unit velocity, we may formularize the phenomena we have observed, by writing

$$\text{Force} \times \text{Time} = \text{Mass} \times \text{Velocity} \tag{1}$$

from which we may get by transposition

$$\text{Force} = \frac{\text{Mass} \times \text{Velocity}}{\text{Time}} \tag{2}$$

$$\text{Time} = \frac{\text{Mass} \times \text{Velocity}}{\text{Force}} \qquad (3)$$

$$\text{Mass} = \frac{\text{Force} \times \text{Time}}{\text{Velocity}} \qquad (4)$$

$$\text{Velocity} = \frac{\text{Force} \times \text{Time}}{\text{Mass}} \qquad (5)$$

The product of "force" into "time" is called "impulse," and the product of "mass" into "velocity" is called "momentum"; the equation teaches us that an "impulse" is equal to the "momentum" which it produces.

It is chiefly with the practical application of the laws we have just enunciated that we have to do in regulating the speed of water-wheels.

Let us examine still further into the matter. We know that if we let any weight fall freely under the force of gravity,—or, as it is usually written, with a force $= g$,—at the end of one second it will have acquired a velocity of approximately 32.2 feet per second; or, if we throw any weight up with an initial velocity of 32.2 feet per second, the force of gravity will stop it in one second.

In the latter case, the velocity at the start = 32.2, and the velocity at the end of the second = 0, and the mean or average velocity and the distance it will travel $= 32.2 \div 2 = 16.1$ in the first second. Therefore, the work in foot pounds, which any weight can do by being thrown vertically with an initial velocity of 32.2 feet per second = weight $\times \frac{g}{2}$ feet.

Please note that in above case, the initial velocity $(V) = g$ or 32.2, and that $V \div g = 1$.

If, however, we have thrown the weight upward with an initial velocity twice as great as before: *i. e.*, 64.4 feet per second, the force of gravity would stop it in two seconds; but the mean velocity in this case is $64.4 \div 2 = 32.2$, which is twice what it was before, and we must also note that it was traveling upward twice as long as before; hence, by doubling both the velocity and the length of time, it will ascend four times as far. Thus, by doubling its $V \div g$, which in the latter case $= 2$, we have enabled the weight to do four times the work. Or, we may truthfully state that in the second case the work equals that in the first case multipiied by $(V \div g)^2$; or, formulating it

$$\text{Work in foot pounds} = \text{weight} \times \frac{g}{2} \times \left(\frac{V}{g}\right)^2 \qquad (6)$$

$$\text{Work in foot pounds} = \text{weight} \times \frac{g}{2} \times \frac{V^2}{g^2} \qquad (7)$$

$$\text{Work in foot pounds} = \text{weight} \times \frac{V^2}{2\,g} \qquad (8)$$

or we may more conveniently write it

$$\text{Work in foot pounds} = \frac{\text{Weight}}{g} \times \frac{V^2}{2} \qquad (9)$$

which is the form in which we will have occasion to most often use it.

As this is a universal law applicable to any force and any velocity it is applicable to water falling under the influence of gravity.

To fix it in our minds let us apply it numerically to the masses with which we have been experimenting. Start with the masses as shown in Fig. 2.

Let the masses M and M_1 be equal, and let them each be numerically equal to 1. Let $F = 2$ and $F_1 = 4$. Let their time of action $T = 1$ second, then their velocities at the end of the time T will be

$$V = \frac{F\,T}{M} = \frac{2 \times 1}{1} = 2$$

$$V_1 = \frac{F_1\,T}{M_1} = \frac{4 \times 1}{1} = 4$$

Now at the end of the time T, stop the action of the forces F and F_1 and apply to the masses M and M_1 in an opposite direction a new force $F_2 = 2$. This new force will stop the masses in the following lengths of time:

$$T_1 = \frac{M \times V}{F_2} = \frac{1 \times 2}{2} = 1$$

$$T_2 = \frac{M_1 \times V_1}{F_2} = \frac{1 \times 4}{2} = 2$$

But the space S_1 and S_2 through which they will travel before they stop will be

$$S_1 = \frac{V T_1}{2} = \frac{2 \times 1}{2} = 1$$

$$S_2 = \frac{V_2 T_2}{2} = \frac{4 \times 2}{2} = 4$$

or the masses are as	1 : 1
and the forces applied to them are as	2 : 4
for lengths of time which are as	1 : 1
which give them velocities which are as	2 : 4
and cause them to travel through spaces	
which are, during time T, as	1 : 2
consequently doing work on them which are as	
$\left(1 \times \frac{2 \times 2}{2}\right) : \left(1 \times \frac{4 \times 4}{2}\right)$ or as	2 : 8
They can then oppose equal forces	
through spaces which are as	1 : 4
during lengths of time which are as	1 : 2
consequently doing amounts of work which are	
as $F S$ and $F S_1$ or $(2 \times 1) : (2 \times 4)$ or	2 : 8

In the above case the masses M and M_1 should consist of weights of 32.2 lbs.; that is, the weight at each end of the wire should be 16.1. The force $F = 2$ lbs., $F = 4$ lbs., $F_2 = 2$ lbs. A pendulum 39.1 inches long from center of weight to point of support will beat near enough seconds for ordinary experimental purposes. A few experiments carefully carried out with the apparatus shown in Figs. 1, 2 and 3 will teach one more about the relations of mass, force, time and velocity than can readily be learned in any other way.

We are now prepared to see the application of the laws, and the formulæ we have written, directly to one of the most important details connected with the installation of water-wheels. This can be best shown by an example.

We have here two water-wheels (Fig. 4) operating under the same head, which we will assume to be nine (9) feet. You will observe that although the head is the same in both cases, one wheel,—which we will designate No. 1,—is set in an open flume of ample size; while the other wheel,—which we will designate as No. 2,—is in a closed flume connected to open water by a long

closed pipe which is nearly horizontal. The behavior of these two wheels when operating under variable load, is entirely different.

Let us assume, for the purposes of argument, that the efficiency of the wheel is the same at all stages of gate, and that the amount of water which passes through the wheel is proportional to the gate opening, and that the power of the wheel is proportional to the amount of water which passes through it under constant pressure. Now, if the wheel is operating at full gate and half the load is suddenly thrown off, and the suitably designed governor attached to the wheel promply shuts the gates so that only one-half as much water can pass as when the wheel was at full gate, it is evident that the speed will remain comparatively constant.

Let us see if this will be the case with wheel No. 2. If it is operating at full load, and half the load is instantly thrown off, and the governor promptly shuts the gates so that only half as

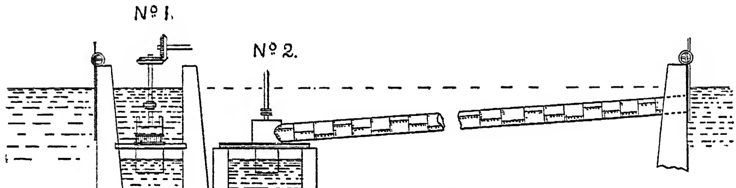


FIG. 4.

much water can pass, it is evident that the velocity of the water in the closed pipe must be reduced one-half.

If we assume that the water in the pipe weighs 1,000,000 pounds, and has a velocity at full head of four feet per second, its energy (see formula 9) $= 1{,}000{,}000 \div 32.2 \times 4^2 \div 2 = 248{,}440$ foot pounds, and if the water velocity at half load is two feet per second, then its energy $= 1{,}000{,}000 \div 32.2 \times 2^2 \div 2 = 62{,}110$ foot pounds, and the difference between these two amounts of energy, $248{,}440 - 62{,}110 = 186{,}330$ foot pounds, must be expended upon the water-wheel before the water velocity is reduced to two feet per second.

If it were expended in one second it would $= 186{,}330 \div 550$ horse power, but this is a little quicker than we would expect to do in practice. Suppose we slow up the water column in two seconds, then the energy expended $= 186{,}330 \div 550 \times 2 = 169$ H. P. for two seconds. The above value of H. P. would not hold strictly true unless the rate at which the gate closed was pro-

portional to the rate at which the water column slowed up; but the total foot pounds expended on the wheel would be as above stated. To find the exact value of H. P. at any instant of time, would require a more elaborate mathematical treatment of the problem than the time now at our disposal permits; but the significant fact to which I wish to call your attention is that this work done upon the water-wheel in slowing up the water column, is entirely independent of, and in excess of, the work which is expended upon the water-wheel when it is working normally at half gate, with the water column moving at a fixed velocity.

It is evident that the above amount of work done upon the wheel while the water column is slowing up, would tend to make the speed of the water-wheel run high if the governor only half closed the gates. In fact, the governor would have to set the gates much nearer closed than one-half; or, to speak more accurately, the governor would, at each instant of time, have to hold the gates at such a position that the power developed by the wheel, due to the working head plus the instantaneous value of power being developed by the slowing water column, equalled the load upon the wheel.

This might be found to be quite unfeasible, for the pressure developed on the closed pipe and wheel case might be dangerous, or the gate might be too ponderous or too badly rigged to permit of the requisite promptness of motion.

The maximum pressure which would be developed at any instant of time at the water-wheel, would be an impossible thing to calculate without knowing a great deal more about the venting areas and time-ratio of closing them than can ordinarily be found out in practice. All that can be predetermined is what may be called, for want of a better term, the time-average pressure. This can easily be determined as follows:—

Let P = the time average pressure

L = the length of the closed flume in feet.

V = the water velocity in feet per second.

T = the time in seconds in which the water velocity is arrested.

K = the area of a square inch expressed in square feet = .00694.

Then

$$P = \frac{K \times 62.4 \times L \times V}{32.2 \times T} \tag{10}$$

It will be observed that

$$\frac{K \times 62.4}{32.2} = .01324 \text{ is a constant, call this } K_1$$

and the formula becomes

$$P = \frac{K_1 \times L \times V}{T} \tag{11}$$

Applying this to the flume we have been discussing in which

$$L = 300$$

$$V = 2$$

$$T = 2$$

we have

$$P = \frac{.01324 \times 300 \times 2}{2} = 3.97$$

As a water column one foot high exerts a pressure of .43 lbs. per square inch, it follows that a pressure of 3.97 lbs. per square inch represents a head of $3.97 \div .43 = 9.2$ feet. In other words, if the pressure on the wheel could have been kept constant all the time the water column was slowing up from four feet per second to two feet per second, the wheel would have been working under $9 + 9.2 = 18.2$ feet of head, instead of under 9 feet of head as it should have been.

From experience we know that it is impossible to close the water-wheel gates at such a rate as to keep the pressure constant, and as a matter of fact, during some portion of the two seconds the water pressure would have been greatly in excess of 3.97 lbs. per square inch above normal, with a correspondingly large disturbance of the speed.

We may note a curious fact in this connection. With a water-wheel set like No. 2 in Fig. 4, working at nearly full gate, and if under these conditions a large portion of the load is instantly thrown off and the governor is of unsuitable design and does not compensate for the kinetic energy of the slowing water column, it may be found by experiment that the speed will run higher than though there were no governor at all. This is for the reason

that for an interval of time the wheel is working under light load and a greatly increased head, and there is, consequently, a greatly increased speed; or, we may say that the amount of energy applied to the wheel under the increased pressure, even though the gate areas have been somewhat reduced by the governor, is greater than would have been the case had the gates not been moved at all.

The first remedy which suggests itself is to place large relief valves near the wheel case, so that they will open and let the water escape if the water much exceeds the static head. This would help matters somewhat upon load suddenly going off, but would it help matters upon load suddenly going on? Let us examine this matter.

Suppose the wheel is working at half load with the water column moving at a rate of two feet per second, and the whole load is instantly thrown on the wheel. The governor will promptly open the gate wide, but the water-wheel cannot develop its whole power until the water column has attained a velocity of four feet per second. To gain this extra two feet per second the water column must have expended upon it the same amount of work which it expended in losing its two feet per second, namely, 186,330 foot pounds, and this must be deducted from the work the wheel will do normally at full gate; so that the instantaneous value of power developed by the wheel while the water column is gaining velocity would equal the normal power of the wheel at full gate minus the instantaneous value of power being expended upon the water column in getting up to speed.

It is evident that the speed of the water-wheel would fall considerably below normal and there would be absolutely no remedy for it in the present state of the art. I say this advisedly and have not forgotton the question of fly-wheels, which is undoubtedly in all of your minds at the present moment.

Let us now consider how long it will take the water column to get up to speed. First let us look again at wheel No. 1 for a moment. We know that the velocity of water falling without friction may be expressed by the formula.

$$V = \sqrt{2\,g \times H} \tag{12}$$

where $V =$ velocity in feet per second.

$g = 32.2$

$H =$ head in feet.

taking $2\,g$ outside of the square root sign we have

$$V = 8.025\ \sqrt{H} \tag{13}$$

This is the velocity with which water should enter the water wheel.

For purposes of simplicity I have in this paper ignored the corrections which should be made for water friction on surfaces and in orifices, as they do not alter to any large extent the stubborn facts we are considering. Such corrections are beyond the scope of this paper.

Applying formula No. 13 to wheel No. 1 and assuming that the water enters the wheel without friction we have

$$\left.\begin{array}{l}\text{Velocity of water entering}\\ \text{wheel under 9 foot head}\end{array}\right\} = 8.025\ \sqrt{9} = 24 \text{ ft. per second.}$$

Now, as the time required for a falling body to acquire a given velocity $= \dfrac{V}{g}$ we find in the case of wheel No. 1.

$$\left.\begin{array}{l}\text{Time in seconds for water to}\\ \text{acquire spouting velocity into}\\ \text{wheel under 9 foot head.}\end{array}\right\} = \frac{V}{g} = \frac{24}{32.2} = .7 \text{ second.}$$

Thus, if the gates being closed were instantly opened, the water would be doing its full amount of work on the wheel in seven-tenths of a second.—To make the above absolutely true it would be necessary to assume that the water would enter the wheel with equal freedom at all stages of gate, which is not the case, but it is sufficiently near the truth for our present argument. We are also ignoring what is known as the velocity of approach for reasons previously stated.

To make sure that our figures are right let us calculate the value of V from our fundamental equation (No. 5.)

$$V = \frac{F\,T}{M}$$

Assume a vertical water column of one sq. ft. area and 9 ft. high. Its weight is $62.4 \times 9 = 560.7$: this $= F$.

Then

$$V = \frac{561.6 \times .7}{\dfrac{561.6}{32.2}} = 22.6$$

which is a close approximation to the value of $V = 24$ previously

found, the slight discrepancy being due to the fact that 62.4 is not the exact weight of a cubic foot of water, and 32.2 is not the exact value of g. It might also be added that the square root of $2\,g = 8.025$ which is usually given in books on hydraulics, and which was previously given in formula No. 13 is a trifle too large, and a closer approximation to truth will be obtained by calling it 8.02. By using better values we can bring out $V = 23.8$

Now, in case of wheel No. 2 the water will behave in an entirely different manner. We know that the spouting velocity at wheel No. 2 is the same as at wheel No. 1 minus the friction of the pipe. Unfortunately, we are concerned not only with the spouting velocity at wheel No. 2, but with the length of time it will take to attain spouting velocity at wheel No. 2. The water, instead of falling vertically as in wheel No. 1, runs down an almost horizontal inclined plane. A large part of the force of gravity is applied perpendicularly to the inclined plane and the small remainder is applied to shove the water down the inclined plane. A diagram will make this clear.

Let A in Fig. 5 = the head in feet from open water above the entrance to the flume to tail water level.

Let B = the horizontal distance in feet from entrance to flume to draft tube at tail water level.

Then C = the hydraulic slope.

Project $C_1 = A$ = the hydrostatic head.

Draw D perpendicular to C.

Complete the parallelogram.

Then the force C_1 (which we must remember is the hydrostatic head) is equal to the forces A_1 and D of which the latter is wholly sustained by the reaction of the plane C_1 while A is wholly effective in accelerating the motion of water down the slope C. We evidently wish to know the value of A_1 in terms of the triangle $A\ B\ C$ which is similar to the triangle $A_1\ B_1\ C_1$.

We know that $A_1 = C_1$ sine a_1. Then as $C_1 = A$ and $a_1 = a$ it follows that $A_1 = A$ sine a. Let us designate the value of A_1 so found as f.

We have seen (Fig. 3) that the time to give equal masses equal velocities is inversely proportional to the forces.

Calling T the time to acquire spouting velocity down A and T_1 the time to acquire spouting velocity down C we may write

$$T : A = f : T_1 \tag{14}$$

from which we get

$$T_1 = \frac{T\,A}{f} \qquad (15)$$

Let us apply this equation 15 to the case of wheel No. 2 in Fig. 4.

The head

$$A = 9 \text{ feet.}$$

Assume

$$B = 298.7 \text{ feet.}$$

Then

$$C = \sqrt{9^2 \times 298.7^2} = 300 \text{ feet.}$$

$$\text{Sine } a = \frac{A}{C} = \frac{9}{300} = .03$$

$$A_1 = A \text{ sine } a = 9 \times .03 = .27 = f$$

$$A = 9$$

$$T = .7 \text{ previously found}$$

then

$$T_1 = \frac{T\,A}{f} = \frac{.7 \times 9}{.27} = 23.3$$

seconds required for water to acquire spouting velocity down slope C.

It may be noted that

$$T_1 = \frac{T\,A}{f}$$

may be written

$$T_1 = \frac{T\,A}{A \text{ sine } a} \qquad (16)$$

which by cancellation becomes

$$T_1 = \frac{T}{\text{sine } a} \qquad (17)$$

which is its simplest form, and in which it should be used.

To make the above reasoning plainer, I have plotted (See Fig. 6) lines showing the time necessary for water to acquire spouting velocities into the two water-wheels shown in Fig. 4. Line 0-1 shows the time for water to acquire any velocity up to spouting velocity into wheel No. 1; line 0-2 shows the time for water to

acquire any velocity up to spouting velocity into wheel No. 2.

It naturally occurs to one in this connection, that the water never has occasion to acquire spouting velocity in the flume of wheel No. 2: in fact, we assumed that the maximum water velocity in this flume was only four feet per second, which is only one-sixth of spouting velocity. It can be shown mathematically, and experiment proves that this does not interfere with the line of reasoning we have been following. If, instead of the end of the flume being wide open, it were five-sixths closed, the remaining sixth being an orifice (the venting areas of the water-wheel) capable of being varied at will, it would simply mean that in the flume the value of $g = 32.2$ would be considerably reduced. This new value we should calculate and call it G. We could then substitute it for the value of g we have been

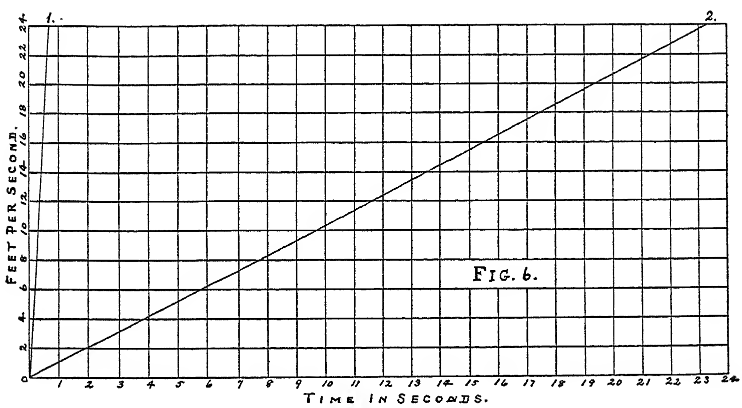


FIG. 6.

using in our calculations, and the ratio of velocity and time in the open flume of wheel No. 1 and in the closed flume of wheel No. 2 would be found to be the same that we have already ascertained.

But it may be argued that we are concerned with the force which the water will apply to wheels No. 1 and No. 2 while the water is getting up to spouting velocity, and not with the velocity of the water itself. Let us see at what rate the water will develop its full amount of energy on the two wheels we have been considering.

The theoretical amount of energy which flowing water can apply to an obstacle, advantageously placed in its path, may be expressed as follows:—

$$P = F + F = 2\ W \frac{V}{g} = 4\ w\ a\ \frac{V}{2\ g} \qquad (18)$$

where P = the theoretical energy developed
F = the force of impulse and also of reaction
W = weight of water flowing per second
w = weight of one cubic foot of water
a = cross-section of the stream in square feet.

It will be noted that if we assume $a = 1$, we may regard

$$\frac{4\ w\ a}{2\ g} = 3.9$$

as a constant, which, multiplied by the square of the velocity of flow in feet per second, will give the theoretical force which the water will develop. I have calculated the force developed at

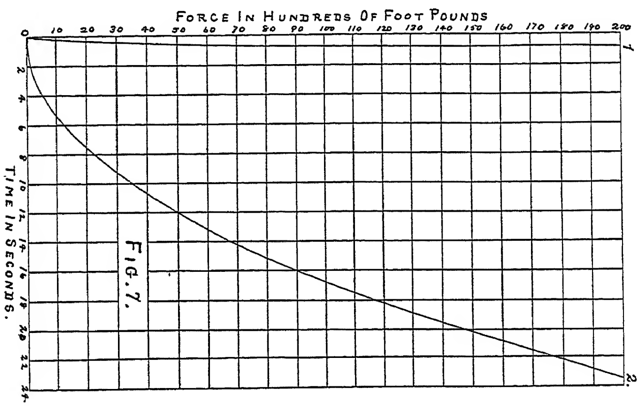


Fig. 7.

wheel No. 1 and No. 2, as shown in Fig. 4, for each tenth of a second, beginning with the water at a rest in both cases and ending with spouting velocity, and have plotted the values in Fig. 7. Curve 0–1 shows the rate at which water standing at a rest, develops its full energy on wheel No. 1: curve 0–2 shows the rate at which water standing at a rest develops its full energy on wheel No. 2. You will note in the case of wheel No. 1, how very promptly the energy gets to its maximum value, and in the case of wheel No. 2, how the energy lags for a considerable time before it arrives at anything like its maximum value.

I wish to emphasize this line of reasoning, because it is, perhaps, the most important thing to be considered in setting water-wheels where speed regulation is a desideratum. We can,

in an imperfect way, provide for the expenditure of the energy necessary to slow up a water column, but there is no way to make a water column, while gaining velocity, do the work it is capable of when it has arrived at full velocity.

The important fact to which I want to especially call your attention is that the difficulty is measured not only by the length of the closed flume, but is inversely proportional to the sine of the angle of hydraulic slope. When the sine becomes 1; that is, when the angle is 90°,—or in other words, when the closed flume is vertical,—then the difficulties due to the fact that water moves slowly under the influence of gravity, have reached their minimum and the speed regulation will be the best obtainable. As the sine of the angle of hydraulic slope grows less, then the obtainable regulation grows worse.

There is one way in which the difficulties attendant upon a small angle of hydraulic slope may be in a measure compensated for, and that is by means of a stand pipe.

In an electric plant, it is not usually of such importance that a load change amounting to the full capacity of the wheels be followed by a small speed variation, as that the comparatively large loads which go off and on for short intervals of time shall not disturb the speed to any great extent. Here is where the stand pipe is of value. If a portion of the load goes off instantly, and the correctly designed governor promptly closes the gates to the correct position, the excess of water will flow out over the top of the stand pipe and the water velocity in the flume will not be arrested so promptly as though there were no stand pipe; neither will the pressure at the wheel be much increased. To obtain these results, the stand pipe should be only a very little higher than the water level in the pond. It should be located as near the wheels as possible, and its top should be turned over so that the escaping water can be led to some convenient point of discharge.

If, after a load has gone off instantly, it comes on again in a short interval of time, it finds the water velocity in the flume but little diminished, and also the vertical water column in the stand pipe is ready to apply its energy to the water-wheel in the most advantageous manner. To make the last factor of much practical use, the cross-section of the stand pipe must be sufficiently large to prevent the level of the enclosed water column from falling much while the water in the closed flume is gaining

its lost velocity. As a general statement, the larger the diameter of the stand pipe and the less its height above the hydrostatic level, the better will be the speed regulation. There has not, as yet, been sufficient practical experience with stand pipes to formulate rules which will solve the least diameter which will result in any desired degree of speed regulation.

In the writer's experience, it has been found that the use of a stand pipe of ample proportions will render a plant governable within very close limits under ordinary operative conditions which had proved to be utterly ungovernable before the stand pipe was installed.

From what has been said above, it will be seen that a stand pipe is chiefly of use in aiding a good governor to maintain a comparatively constant speed under those frequently recurring load changes which obtain in electric plants,—especially in electric railway and power plants. It also gives perfect protection against dangerous water pressures being developed when circuit breakers open, or when, for accidental reasons, it is necessary to shut down the water-wheels instantly.

A stand pipe will not,—unless of very large diameter,—enable a good governor to maintain a good degree of speed regulation if the load be increased from friction load to full load instantly, where the angle of hydraulic slope is small, unless such increase of load takes place before the water in the enclosed flume has lost much of its velocity.

The writer had intended to refrain entirely from submitting designs showing the proper setting of water-wheels, for the reason that such a large number of typical plans would be required to cover all probable cases, that it would be hopeless to to treat the subject properly without extending this paper beyond proper limits. He cannot, however, resist the temptation to introduce at this point, one design (shown in Fig. 8) which has proved to .be singularly adapted to the demands of water-power driven electric plants. It will be noted that the wheels are arranged for direct connection. The angle of hydraulic slope is practically 90°, giving the best possible condiitons for speed regulation. The governor may be placed directly outside the flume head and connected to the gates in the simplest possible manner. The speed variations of the main shaft may be transmitted to the governor by one belt. The requisite R. P. M. may be obtained by varying the diameter and

number of wheels. The number or size of wheels on the one shaft may vary from one to as many as can be handled by one governor, or as may be required by the capacity of the electrical unit. This general design has found favor in a number of the most prominent plants in this country as well as in Europe. The regulation is invariably good if a suitable governor be used.

It is usually the case that part of the head utilized in modern plants is below the water-wheel in the shape of a draft tube: in fact, where horizontal wheels are used, it is practically necessary to have them a number of feet above tail water level for convenience of connection to the driven machinery.

The same general rule holds good in regard to draft tubes, which, we have found, applies to closed flumes. They should be as short and as nearly vertical as possible. The maximum

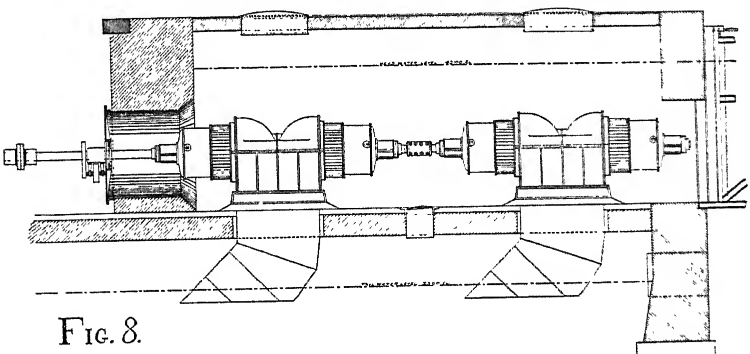


FIG. 8.

vertical length of a draft tube is, of course, limited by the atmospheric pressure. The water stands in the draft tube for the same reason that mercury stands in a barometer. The specific gravity of mercury is 13.6: that is, it is 13.6 times as heavy as water. Atmospheric pressure holds mercury up in the barometer tube,—let us say 30 inches or $2\frac{1}{2}$ feet,—therefore it will hold water up in the draft tube $2.5 \times 13.6 = 34$ feet: that is, it would do so if the draft tube were air tight. The external atmospheric pressure at the top of such a draft tube would be 14.7 pounds per square inch. There are few draft tubes that would stand that pressure without leaking air. This fact is well recognized by hydraulic engineers, and it is rare to find draft tubes 25 feet high from tail water level to water wheel centers. If the water-wheel is likely to be subjected to large load varia-

tions, it is very desirable that the draft tube should have a much less vertical height for the following reason :—

At the bottom of a 25-foot vertical draft tube the atmospheric pressure is forcing the water up with a pressure of 14.7 pounds per square inch, and the weight of the water is pressing down with a pressure of 10.75 pounds per square inch: that is, the difference between the air pressure and the weight is 14.7—10.75 =3.87 pounds per square inch. Now, if the water velocity in the draft tube is suddenly arrested by shutting the water-wheel gates the kinetic energy of the slowing water column will be found in the downward momentum of the water. This may easily create a downward pressure greater than 3.87 pounds per square inch, in which case a vacuum would be formed in the upper part of the draft tube and the column of water would sink in the draft tube and immediately after would rush upward again striking the bottom of the wheel with great violence. If we were so fortunate as to escape an accident of the kind above described we should find that with a draft tube of considerable height there is a tendency for air to leak in, and this, under the negative pressure of the weight of the water, expands into a partial vacuum so that the draft tube will be only partly filled with water, and as the position of the water-wheel gates varies as the load changes, the water column in the draft tube will sway up and down producing the effect of a pulsating head on the water-wheel. This is very detrimental to good speed regulation, and is a very common annoyance encountered in practice. The performance of such a draft tube may be easily illustrated by holding a mercurial barometer in the hand and slowly moving it up and down.

Air chambers on flumes, to give protection against water hammer effects, are of very little practical use unless of ample size, even if they are full of air. The writer examined a plant so located that the bursting of the flume would have destroyed the whole plant and ruined an investment of, at least, $100,000. At the lower end of the flume was a large air chamber. The superintendent in charge pointed with pride to it, and confidently expressed the belief that it afforded ample protection against the dangerous strains on the flume due to water hammer. Upon examining the air chamber it was found to be entirely filled with water, and it had probably been in that condition for a considerable length of time. Water under pressure absorbs air with great facility. An air chamber should be provided with an air pump

which may be readily connected to some convenient source of power, and with a gauge glass to show the water level. When so arranged, and if of ample size, it affords considerable safety against pressure developed when load goes off suddenly; but it is of no practical use as an aid to the governor in maintaining constant speed.

Aside from designing the water column along the lines already suggested, so that the water may gain its working velocity in the least possible time and also so that it may add to or take from the water-wheel the least amount of the kinetic energy of the water, the next most important thing is the design of the water-wheel gates and the method of connecting them to the governor.

As has already been pointed out, the gates are of necessity large and heavy, and yet they must be moved with great promptness and precision. The writer has had occasion to investigate with more or less accuracy the number of foot pounds necessary to open and close the gates of several hundred water-wheels, and the surprisingly large variation in the amount of energy required, leads him inevitably to the conclusion that this matter has not received in many cases the careful engineering treatment which it deserves.

Water-wheels are of many designs and sizes, and work under many different conditions of head, but there would seem to be no adequate reason why the gate of one water-wheel developing a certain amount of power under a given head should require only 1,000 foot pounds to completely open it, and the gate of another water-wheel of different make, developing the same amount of power under the same head, should require 60,000 foot pounds. Yet such has been found to be the case. The above example, taken from actual practice, is by no means unusual; and scores of such cases could be cited showing relatively absurd figures.

Some builders prefer to use cylinder gates on their wheels; others prefer wicket gates; while still others adhere to register gates. It is not the intention of this paper to enter into a critical comparison of the merits of these various types of gate, and, in fact, from the standpoint of speed regulation, no such comparison is necessary for the good and sufficient reason that there are wheels on the market of all three of the above kinds which show little to be desired in the ease with which the gates may be moved. It is also true that there are makes of wheels of all

three kinds which cannot be governed accurately under variable loads, simply for the reason that their gates cannot be moved quickly enough.

It is often necessary to start a gate from a rest and completely open or close it in two or three seconds, or give it a proportionately smaller motion in a proportionately shorter space of time. Or, what is still more severe, it is often necessary that while a gate is opening or closing, its motion be instantly stopped and reversed.

If one will watch a thoroughly first-class governor handling the gates of a water-wheel which is driving an electric generator operating on a variable load, one is convinced of the fact that the governor has to develop considerable amounts of energy in surprisingly short spaces of time, and that the rigging connecting the governor and the gates is subjected necessarily to considerable strain, from which it follows that the easier the gates move the less chance there is of stripping gears and twisting off shafts; to say nothing of relieving the governor itself of unnecessary strain.

All gears between governor and gate,—except immersed racks and pinions,—should be cut, of first class workmanship and not too large for the work required of them. The latter precaution is necessary to prevent the MV^2 energy in the gears themselves destroying the rigging when the direction of motion is suddenly reversed. Shafts should be of just sufficient size to give an ample factor of safety, and prevent torsional difficulties, for it is absolutely necessary that the smallest amount of motion of the governor shall be transmitted accurately to the water-wheel gate. Lost motion in gears, and twisting of shafts are fatal to good regulation. Hand-wheels should be so arranged that they may entirely thrown out of connection with the rigging while the governor is in action, or they may be unkeyed in some simple manner.

Counterbalancing a gate is not the equivalent of having it in water balance. All vertical cylinder gates are necessarily out of balance to an amount equal to their immersed weight, but that is usually so small that it is not necessary to counteract it with a counterweight.

Some designs of gate show a violent tendency to close or stay closed. It is the custom to counterbalance such gates, and this practice leads to endless trouble an account of the kinetic energy

in the counterweight. It being often necessary to reverse the motion of the counterweight suddenly, the kinetic energy expended at the moment of reversal, is often sufficient to wreck the rigging. If counterweights must be used, it should be remembered that their kinetic energy is proportional to their weight, and also proportional to the square of their velocities; from which it follows that a heavy, slow-moving weight does less damage than a light, rapid-moving one.

Some general statements may be made in regard to the design of water-wheel gates adapted to plants in which it is desirable to obtain good speed regulation.

It has been the custom of late to cast onto cylinder gates, fingers reaching out between the guides. These innocent looking devices, which are supposed to guide the water into the wheel properly, and hence raise its efficiency, are a source of no end of trouble when it comes to moving the gate quickly enough to produce good speed regulation. The direction of motion of the water as it enters the wheel is always such that it presses these fingers downward with tremendous force, giving the gate a strong tendency to close. By removing these fingers, the amount of energy necessary to open the gates can always be reduced by, at least, one-half, and often times more than that. There are scores of water-wheels on record which were so much out of balance, due to the fingers on the gates, that it was found impracticable to govern them satisfactorily on acount of gears stripping and shafts twisting off. In the writer's experience, it has always been found practicable to govern these wheels by removing the fingers.

Now, as to the question of efficiency. The writer has often had to meet the argument of the few per cent. of efficiency supposed to be lost by removing these fingers, and to answer this question, tests have been made which show that there is no material gain in the efficiency of a water-wheel set under ordinary working conditions, by attaching fingers to the gate.

Two vertical cylinder-gate wheels of the same size and make, were set in open flumes side by side. The head was precisely the same in both cases. Both wheels drove electric generators of the same make, type and size. Both wheels were furnished by the maker with cylinder gates, precisely alike and provided with fingers. It was found impracticable to govern these wheels properly, on account of the gates working so hard and being so

much out of balance. The fingers were removed from the gate of one wheel, and it was at once found that the wheel governed very satisfactorily under a very variable load. Then a test was made of the efficiency of the two wheels, one with, and one without fingers on the gates. Wires were brought up from the gates, carried over pulleys, kept taut by small weights, and they terminated in pointers reading on the same scale. A constant electrical load was switched onto one generator, and the position of the pointer indicating gate position was noted. Then the load was switched onto the other generator (the speed being kept the same in both cases) and it was noted that the pointer of the second unit stood at the same point at which the pointer of the first unit had previously stood. This experiment was repeatedly tried at a number of different loads, from slightly above friction load, to nearly the full capacity of the wheels. So far as could be observed, the efficiency of the wheel without fingers on the gate, was as good as that of the wheel with the fingers. The particular test above described, was made by Mr. J. H. Wilson, in the plant of the Berlin Mills Co., Berlin Mills, N. H.

The writer is aware that this test is not the equivalent of a Holyoke test, but it is certainly of great interest to the practical engineer who is harassed by the thought that in avoiding the Scylla of bad effiiciency, he will surely be wrecked on the Charybdis of an ungovernable gate.

There are a number of other details of cylinder-gate construction which-time and space will not permit us to touch upon here, but which should be considered by the thoughtful engineer before making a selection. The thing to be borne in mind is that the cylinder and its connections should be of such design that they may be easily moved, and will not bind and run hard in any portion of their travel.

Wicket gates also have their peculiarities. Some makers hang them in such a manner that thay are practically in water balance in any position, and may be readily opened and closed with a small expenditure of energy. Such gates leave little to be desired, and wheels fitted with gates so designed may be governed with the greatest degree of exactness and without fear of injury to the rigging or governor. The writer has observed, however, that some wicket gates which move very easily have so much lost motion that in certain portions they tend to flop (no other

word conveys the idea) first in one direction and then in the other, causing a pulsating speed which is very annoying and apparently inexplicable until one has investigated the cause. The danger of lost motion is greater with wicket than with cylinder gates, but with proper construction it is found in practice that lost motion may be entirely eliminated from wicket gates.

In some wicket-gate wheels the wickets are hinged at one end and attached by the other end by tangential arms to a banjo, which in turn is geared to the shaft going to the governor. Such gates are entirely out of water balance when partly closed, and the more they are closed the more they are out of balance. Wheels with gates of this description are very difficult to govern. Frequently the strength of the wickets and radial arms is not sufficient to withstand the water pressure, even if sufficient energy can be supplied to them. In recent practice a wheel of this description was found to require some 40,000 foot pounds to open it. Another wicket-gate wheel of different make but the same rated H. P. was found to require only 5,000 foot pounds to open it. As another recent instance, it was found that a pair of wicket-gate wheels of the kind described above required 19,000 foot pounds to open them: another pair of different make but the same rated H. P. required but 2,500 foot pounds to open them. The wheels compared above were working under the same head.

The way a maker proposes to rig his gate is a good indication of the amount of energy he thinks it will take to move it. If he thinks it is necessary to use worm gears or multiplying gears giving a large number of turns to the hand-wheel it is safe to conclude that in his opinion,—and he certainly ought to know,— the gate will move hard or be much out of balance. Such wheels it is safe to leave alone if accurate speed regulation under variable load is the end in view.

All practical engineering is a compromise between the desire of the engineer on the one hand to produce a perfect piece of engineering, and the unwillingness of the stockholders on the other hand to invest money which will not bring direct returns in the shape of dividends, or, to state the matter more conservatively, there is always a point in each plant beyond which investment must not go, and this point is different for each plant, being fixed by the economic conditions which surround the particular enterprise.

For the above reasons it is impossible to lay down hard and

fast rules for the development of water powers. Assuming that the value of all engineering is measured by the dividends earned, what would be good engineering in one case is bad engineering in another. Yet, it is equally true that in an electric plant driven by water power the worst possible place to economize is in the channels and conduits which bring the water to and away from the water-wheels, and in the water-wheels themselves and their governors. Dollars saved here are apt to be expensive economy.

The infinite variety in which natural water powers present themselves makes this a difficult branch of engineering, and much is yet to be learned about it. Yet, it is safe to say that enough is now known about the subject to permit almost any naturally good water power to be so developed and utilized that the plant driven by it may be as readily controlled and its speed maintained as constant as though the driven load were carried by first-class steam engines. It should, however, be remembered that no matter how well the plant is designed, good speed regulation cannot be obtained unless the water-wheel governors are of correct design and well built. The value of a governor is measured by two things—the promptness and ease with which it will move the water-wheel gates to the correct position and stop them when they get there, and its ability to compensate by adjustment of the gate for the kinetic energy in the moving water column. One might add sensitiveness as a mark of a good governor, but nearly all modern governors are very sensitive, though most of them sadly lack the other two qualifications named above. The best made governors on the market will begin to move the water-wheel gates before any tachometer on the market will show a change in speed, yet they would not govern if they did not know when to stop as well as when to start.

I have been requested by a number of gentlemen to say something about fly-wheels. We may approach this subject in the following manner:—

When we wish to find out how much energy is stored in a revolving fly-wheel we begin by finding its moment of inertia, which is its weight multiplied by the square of its radius of gyration.

Let J = radius of gyration in feet.

W = weight in pounds.

I = moment of inertia.

$$I = W J^2 \tag{19}$$

The energy in foot pounds stored in the revolving wheel is as follows:

Let

$\mathcal{E}$ = energy stored in the wheel.

a = angular velocity in radians per second $= \dfrac{2\, n\, \pi}{60}$ (20)

where

n = revolutions per minute

and

$\pi = 3.14159$

Then

$$\mathcal{E} = \frac{I\, a^2}{2} \tag{21}$$

Substituting the value of a we get

$$\mathcal{E} = \frac{I \left(\dfrac{2\, n\, \pi}{60}\right)^2}{2} \tag{22}$$

Evolving which we get

$$\mathcal{E} = \frac{I\, n^2\, \pi^2}{1800} \tag{23}$$

Which is the form in which the formula is ordinarily used. It may be simplified for

$$\frac{\pi^2}{1800} = .00551 \text{ is a constant.}$$

Substituting this we get (24)

$$\mathcal{E} = I\, n^2 \times .00551$$

But you will note that this expression may be conveniently divided into two parts, as follows:

$$\mathcal{E} = n^2 \times (I \times .00551) \tag{25}$$

Which is equivalent to saying that every fly-wheel possesses a certain quantity, which, multiplied by the square of its revolutions per minute, equals the foot pounds of energy stored in it. This quantity is its ($I \times .00551$) which we may symbolize by $\mathfrak{M}$ and we may write

$$\mathfrak{S} = n^2 \mathfrak{M} \tag{26}$$

Or, substituting our value of I we may write

$$\mathfrak{S} = n^2 \left(W \times J^2 \times .00551 \right) \tag{27}$$

It is evident that this value of $\mathfrak{M}$ which is the energy stored in the wheel when making one revolution per minute when once found for any particular fly-wheel may be used at once to calculate its energy at any speed, simply by multiplying it by the square of its revolutions per minute.

This value of $\mathfrak{M}$ for the rim of any fly-wheel may be found as follows:

Let

w = weight in pounds of one cubic foot of the metal of which it is made.

d = outside diameter of rim in feet.

d_1 = inside diameter of rim in feet.

ℓ = face of rim in feet.

Then

$$\mathfrak{M} = \frac{w\, \ell\, (d^4 - d_1^4)}{59.814} \tag{28}$$

But a close enough approximation to the $\mathfrak{M}$ of a cast-iron flywheel of usual shape with light arms may be found as follows:

Let

W = weight of wheel in pounds

d = mean diameter of rim.

Then

$$\mathfrak{M} = \frac{W\, d^2}{23{,}000} \tag{29}$$

Now the question is how much of a fly-wheel do we require in any particular case. Let us return to wheel No. 1 in Fig. 4.

We remember that when the gate of this wheel was suddenly opened wide it was .7 second before the water was doing its full amount of work on the runner. We must also remember that the curve 0 – 1 (see Fig. 7) with which the water got up to full power was a parabola. The area outside the parabolic line was the work which the water did do in this .7 second, and the area inside this parabolic line was the work which the water failed to do in the same time. From the law of areas of parabolas it fol lows that the area inside this curve (which is a half parabola) is two-thirds of the area of the rectangle enclosing the curve. Or we may say more simply that while the wheel was getting up to speed it performed one-third of the work which it would have done in the same time had it been working at full gate and full speed.

Let us begin to apply this to the design of a suitable fly-wheel. Assume, for simplicity of calculation, that the water wheel is about 48″ in diameter and at full gate develops 100 H.P. and runs at 75 R.P.M. Let us also assume that it must not, upon the whole load being instantly thrown on or off, run more than 4 per cent. below or above normal. Its minimum speed must be then

$$75 - \frac{75 \times 4}{100} = 72 \text{ R.P.M.}$$

and its maximum speed must be

$$75 + \frac{75 \times 4}{100} = 78 \text{ R.P.M.}$$

We must also remember that it was found that we could not completely open the gates in less than two seconds. Therefore, supposing that the rate of opening the gate was uniform, the average gate opening during the two seconds was only one half, and if the wheel during every instant of time had been developing the full power due to the instantaneous value of gate opening it would have developed only one-half as many foot pounds as though it had been at full gate for two seconds. But we found that the power lagged .7 second behind the gate opening, during, which time it developed only one-third of the power due to the gate opening; hence, for two seconds the wheel developed $\frac{1}{3}$ of $\frac{1}{2}$ the power it would have developed during the same time at full

gate, and for .7 second more it developed $\frac{1}{3}$ of full power. Reducing this to foot pounds we have

$$\frac{100 \times 550 \times 2}{6} = 18333 \text{ foot pounds.}$$

$$\frac{100 \times 550 \times .7}{3} = \underline{12833} \text{ foot pounds.}$$

Adding these we get 31166 foot pounds, which is the total energy developed by the water-wheel in 2.7 seconds.

If working at full gate and maximum flume velocity for that length of time it would have developed

$$100 \times 550 \times 2.7 = 110000 \text{ foot pounds}$$

Subtracting from this $\underline{31166}$ " "

We get 78834 foot pounds, which is the amount of energy which must be developed by the fly-wheel before its speed is reduced to 72 R.P.M.

Let us assume that the fly-wheel makes the same number of revolutions as the water-wheel.

Its energy at 78 R.P.M. is

$$\mathfrak{M} \times 75^2 = \mathfrak{M} \times 5625$$

Its energy at 75 R.P.M. is

$$\mathfrak{M} \times 72^2 = \mathfrak{M} \times \underline{5184}$$

Subtracting one from the other we get 441

The value of $\mathfrak{M}$ is therefore

$$\mathfrak{M} = \frac{78834}{441} = 178$$

From the above value of $\mathfrak{M}$ should be deducted the $\mathfrak{M}$ of the water-wheel itself and the other rotating parts such as pulleys and armatures. For simplicity of calculation I shall not make this deduction in this case, and we will proceed to design a fly-wheel of suitable proportions, which shall have an $\mathfrak{M}$ value numerically equal to 178.

As it is to be of cast-iron we will limit its peripheral speed to 65 feet per second.

Let d = its outside diameter in feet.

p = its peripheral speed in feet per second.

R = revolutions per minute.

Then

$$d = \frac{p \times 60}{R\,\pi}$$

Applying numerical values we get

$$d = \frac{65 \times 60}{78 \times 3.14}\ 15.5 +$$

Assume d_1 or the diameter inside the rim = 14.5 feet

Transpose formula No. 28 so as to get ℓ or the face of the wheel in feet.

$$\ell = \frac{\mathfrak{M} \times 59814}{w \times (d^4 - d_1^4)} \tag{30}$$

Apylying numerical values we get

$$\ell = \frac{178 \times 59814}{450 \times (15.5^4 - 14.5^4)} = 1.6 \text{ feet} = 1 \text{ ft. } 7 \text{ in. nearly.}$$

Our fly-wheel rim is, therefore, 15 feet 6 inches outside diameter, 6 inches thick, and 1 foot 7 inches wide on the face, and would weigh 16,992 lbs.

This strikes one as a very large fly-wheel for a 100 H. P. unit, but it must be remembered that it is intended to perform very severe duty. Moreover, no allowance has been made for the kinetic energy in the fly-wheel arms, nor in the water-wheel itself and other rotating parts. All of these corrections should be made and the proper deduction made from the fly-wheel above designed.

Another correction should also be made which would still further reduce the size of the fly-wheel.

It was assumed that the water-wheel was working at normal speed and friction load when the whole load was thrown on. Friction load is a part of whole load, and hence when we say we throw on whole load, we really mean that we are throwing on something less than 100 H. P. Also, at friction load the water

in the flume had some velocity, and hence we did not have to start the water from a condition of rest, but from a condition of slow velocity.

To make all these corrections involves a considerable knowledge of hydraulics and mechanics. To treat this subject in a complete manner, would involve a good many figures, and would extend this paper far beyond proper limits.

It may be noted here that if it is found desirable to change the value of $\mathfrak{M}$ of a fly-wheel after it is designed, it is not necessary to re-design the wheel. The dimensions of fly-wheels are as the fifth roots of their $\mathfrak{M}$'s. We have found a fly-wheel whose $\mathfrak{M} = 178$. If we now wish to reduce its $\mathfrak{M}$ to 150, we write

$$\sqrt[5]{178} : \sqrt[5]{150} = 15.5 : \text{diameter}$$

From which we get

$$\text{diameter} = \frac{\sqrt[5]{150} \times 15.5}{\sqrt[5]{178}} = 15.0 \text{ feet.}$$

or formularizing it we get

$$D_1 = \frac{\sqrt[5]{\mathfrak{M}_1} \times D}{\sqrt[5]{\mathfrak{M}}}.$$

Where

D = diameter of wheel having given $\mathfrak{M}$

D_1 = diameter of required wheel

$\mathfrak{M}$ = given value of $\mathfrak{M}$

$\mathfrak{M}_1$ = required value of $\mathfrak{M}$.

All of the linear dimensions should be treated in the same way. For example: if we have a design of a fly-wheel drawn to a scale of one inch to the foot, and in building the wheel we read the drawing as though it were one-half inch to the foot, then the $\mathfrak{M}$ of the fly-wheel will be $2^5 = 32$ times as large as it would have been if the wheel had been built according to the scale of one inch to the foot.

Where we have a fly-wheel of a given $\mathfrak{M}$ and we know how many foot pounds it will be required to give up or absorb, as the case may be, we may find the resulting speed by the following formula:

$$r = \sqrt{\frac{\mathfrak{E} - \mathfrak{E}_1}{\mathfrak{M}}} \tag{32}$$

where r = the final revolutions per minute.
$\mathfrak{E}$ = energy in foot pounds stored in wheel at normal speed.
$\mathfrak{E}_1$ = energy in foot pounds required of the wheel.
$\mathfrak{M}$ = energy in wheel when making one revolution per minute.

The above formula may be more conveniently as follows:

$$r = \sqrt{\frac{(\mathfrak{M} \times R^2) - \mathfrak{E}_1}{\mathfrak{M}}} \tag{33}$$

where R = normal revolutions per minute. Applying to the wheel we have been discussing we have

$$r = \sqrt{\frac{(178. \times 75^2) - 78{,}834}{178.}} = 72$$

which is the minimum revolutions per minute which we first agreed upon.

We have seen that to make even an approximate design of fly-wheel we have required considerable data to work from, and have been obliged to do quite a little figuring, and yet the water-wheel in question was set in the simplest possible manner. Had it been set in a closed flume like wheel No. 2, (Fig. 4,) the problem would have been greatly complicated.

In view of these facts, it becomes quite amusing to note the alleged accuracy with which statements are often made in regard to the exact amount of fly-wheel which is required to give stated degrees of speed regulation upon 10%, 25%, 50%, etc., of the load being instantly thrown off or on, when it is perfectly evident that only part of the data is available which would enable only approximate figures to be made.

The one concluding crumb of comfort which the writer is able to offer, is found in the fact that in a very large practice, he

has never found it necessary with a water-wheel set in an open flume, to install a fly-wheel in order to obtain a perfectly satisfactory speed regulation under any operating conditions of an electric plant. The various rotating parts of the plant, such as water-wheels, armatures, pulleys, etc., have sufficient moment of inertia and angular velocity to enable a first-class governor to hold the speed within very satisfactory limits under any sudden load changes which occur in the actual operation of the plant.

If the design of the hydraulic part of the plant is bad, it is wiser to try and improve it, rather than lean largely on fly-wheel effect, which is a weak prop at the best.

Discussion.

Mr. Charles F. Hopewell:—I would like to ask if the length of the draft tubes makes any difference.

Mr. Garratt:—As a matter of practical experience I have found the more of the head you have above the wheel and the less below it the better the regulation you can obtain, for the practical reason that when wheel builders don't make things tight, and when the pressure is from the inward outward it simply means that a little water leaks out, but when the pressure is the other way it means that the air leaks in. The more air you can keep out of your pipes the better regulation you will invariably get. There is no danger of air getting in above the wheel, but very great danger of it getting in below the wheel. So that it is well to put as much of the head above as you can.

Prof. W. S. Aldrich:—Almost all of the cases given here relate to the reaction or pressure type of wheel. Of course, that is the most difficult to govern. The ordinary impulse water wheel is most easily controlled. The paper evidently proposes to consider only the type of wheels of the reaction or pressure kind. In the western states, wheels are being operated under very high heads which have brought out characteristic methods of speed regulation. Again, methods of regulation such as by throttling the discharge, have been adopted for the reaction or pressure wheels that are suitable only to that type and to be noted particularly in the Niagara plant. But the references in the paper relate entirely to methods of regulation affecting the flow.

The views shown on the screen were of a relay type of governor, a type not proposed for discussion in the paper, but which is coming into more general use for flow regulation of low and medium heads on pressure wheels. Regulating water-wheels by controlling the discharge is, of course, more particularly adapted to installations of the Niagara class; but there seems no reason why it should not be successfully employed in

similar cases of smaller magnitude. It is a method of regulation not taken up in this country to any great extent on account of our very different system of manufacturing turbines. The American method is to carry stock turbines subject to telegraph order, particularly in the smaller sizes, and much in the same way as steam-engines and dynamos are held in stock. It is, therefore, a simpler thing to fit the turbine with a governor controlling the flow of water from the flume, than to make a special design of governor adapted to control the discharge.

With regard to the length of draft tube it is possible to employ, I believe they have been used 28 feet long. Twenty-four or 25-foot lengths seem thoroughly feasible if there are not very great fluctuating loads.

The matter of unsteadiness or hunting action of these water-wheels is a very difficult one to overcome, and I can assure you it is not entirely due to the mere question of the governor action alone. It has been pointed out, for instance, that in its operation the governor may be more or less like a pendulum in a condition of unstable equilibrium; unsteady in its operation on the gates, producing a variable supply of water not timed with the load changes that cause the whole plant to race. The load fluctuations I think are more responsible for this hunting or racing than almost anything else.

There are very few governors but will control a slow flow. In fact, it is not desirable to have a governor respond too quickly. Has any limit been found for the sensitiveness, so to speak, of a water-wheel governor in responding to a quick change of load? The question of lag makes the water problem a trying one to the engineer. We have made tests which seem to show that it is almost impossible to meet simultaneously the changes of load in street railway work by any kind of water-wheel governor. The steam-engine has been referred to as being capable of almost ideal regulation by the nature of the working fluid; yet, in this case even, it has been found desirable in some instances so to arrange the governor that the low-pressure cylinder of a compound engine at times of very light load may act as a drag on the high-pressure cylinder. Similarly, one turbine of a pair may be made to act as a brake to prevent sudden fluctuations of the speed at very light loads. It is an open question whether it is desirable to attempt to have any prime mover regulated for simultaneously following the almost instantaneous fluctuations of street railway work, unless such result in more or less permanent changes of load.

In the sketch, Fig. 8, of a plant arranged with a pair of turbines on horizontal shafts, there is a singular draft tube layout. It may be that the very short curved draft tubes were necessary owing to some structural arrangements of the design. Those draft tubes are, no doubt, made as shown, to meet the requirements of a design, which the author has, rather reluctantly it is

true, pointed out, as representative of this class of installations. We should be careful to look at the matter of draft tubes, for it might appear that those shown here are not altogether ideal. The conical arrangement below the older types of vertical draft tubes has here been done away with, the marked curvature of the draft tube itself providing for an easy discharge of the water.

MR. C. W. RICE:—This is a very interesting and valuable paper. In most of the water driven plants the question of regulation is of the greatest importance, and there are very few plants in America that have satisfactory regulation. A requirement in many plants is economical use of water together with good regulation. In many places the reason for the poor regulation has been that restrictions on the use of water have been made. I am more familiar with high heads than low heads. In some, the heads have been as high as 1,700 feet, coming from lakes of small capacity so that the water had to be saved. I would like to know the greatest height that has been attempted so far, using a stand-pipe as an auxilary to the regulation.

MR. GARRATT:—In the first place the tallest stand pipe which has been installed for the purpose of aiding regulation is about 70 feet. Touching the economy of water by throttling it, I will say in the present state of the art it is not feasible to govern tangential wheels in this way because you can't keep a standard pressure. I am carrying on experiments now which I believe will partially rectify that difficulty, but I have not experimented sufficiently to say exactly what can be done. I hope before another summer meeting of the INSTITUTE I can point to some plants where it is perfectly possible to control the flow of water in a long flume without the use of any stand-pipe at all. Ordinary relief valves I will say are of no use.

In regard to the design of these draft tubes shown in Fig. 8 I will say that the old-fashioned draft tube, slightly conical in shape, the cone being an inverted or concave paraboloid, is almost ideally perfect. But it does not conform to commercial requirements. The tail water has got to be thrown right out in one direction. In this design here that I showed on the screen, the tail water was thrown out directly beneath the floor under each generator. This draft tube shown here is far from being ideal, yet it gives the water the right direction and starts it off in the direction it should go. If you have the room underneath you certainly should not use that form of draft tube.

With regard to the promptness with which water should be permitted to enter the wheel when load goes on: it is not my purpose here to criticise other papers on the speed regulation of turbines. I have tried to confine myself to actual practice and not talk about things which might be different if the Almighty had made different natural laws. In my experience I found that the quicker you can move the gate, provided you know enough to stop it at the right place the better the regulation will be. If the theory

of the governor is wrong, the gate may start at the right time even though it don't stop at the right time. But as a matter of practice it is much more important to stop the gate at the right time than to start it at the right time. The limit of time in ordinary turbine practice is moving a gate from wide open to completely shut is two seconds. Though this cannot always be done I can point to plants where wheels as large as 72 inches in diameter are closed in two seconds. At Niagara Falls the regulation is almost identically the same as in another plant I can point to where the head is only five feet. It makes little difference what the height of the water over the wheel is, provided it is directly over the wheel. If properly designed, the wheel is intended to take water at a certain velocity and if it is designed for five feet it should take water at the velocity due to that head, and if two hundred it should take water at the velocity due to that head. In the case of Niagara Falls there is nearly two hundred feet head, and in another plant just south of there are wheels under five feet head. The wheels in both plants are of the same make and the regulation is practically the same. If you turn the feed pipe down flat you immediately introduce a lag in the water while gaining velocity, as I pointed out in my paper.

MR. STEINMETZ:—Thus to resume, the conclusion of the paper is, what those of us who have had anything to do with water-wheels have well noticed that water-wheels cannot be governed perfectly, but the best we can do is to limit the amount of water which has to be stopped and started, to a minimum, and to steady the speed as much as possible by a fly-wheel. This obviously does not apply to the type of high pressure turbine operating at constant flow of water by deflecting nozzle. Here, however, the difficulty appears how to dispose of the deflected stream since at very high pressure it wears rapidly even through thick cast-iron plates.

More serious still than the momentary change of speed during rapid change of load is the liability of oscillation of the speed of the water-wheel, even with small changes of load, causing a hunting of the governing device, and thus a hunting of all synchronous apparatus and sometimes even rotary induction apparatus connected to the circuit, and a hunting of the alternators against each other, where several are operated in multiple.

Suppose the load changes, increasing a few per cent. The governor opens the gate wider, the pressure of the water column and thus the power decreases, and the governor opens the gate still wider until the water column has regained its pressure. But now the gates are open too far, the speed rapidly increases beyond normal and the governor begins to shut off again. This, however, increases the pressure of the water column and thus the power, and causes the governor to shut off still further, thereby ultimately causing the speed to drop and the governor to open again and so on. If now the governor is very sensitive and quick, the governor will over-reach further than the position it

started from and cause an oscillation of speed of increasing amplitude, that is hunting, which usually makes the whole system inoperative. If, however, the governor is supplied with a powerful damping device it acts too slowly for rapid changes of load and thereby makes the operation of the system unsatisfactory. A governor is therefore, necessary, which acts very quickly, as quick as possible, but does not complete its regulating stroke but hesitates and gradually and very slowly settles down into the position corresponding to the changed load without overreaching it.

MR. GARRATT:—For reasons which must be obvious I distinctly said at the beginning of this paper that it was not upon water-wheel governors; hence I ignored that whole subject. If the gentleman wishes I can project upon the screen photographs of the parts of a governor showing how that action is provided for mechanically with the utmost precision. I intentionally avoided that part of the subject.

DR. BELL:—I think this subject is very vital. We have all sorrowed over it. But it is a fact as a matter of practice that in spite of the inherent difficulties of the problem, if the hydraulic conditions are fairly good, it is possible to get a good regulation of the water even in cases where the load is a railroad load and badly fluctuating at that. I have watched the operation of governors and seen railroad plants so operated as to give as good regulation as would ordinarily be got from an engine. Of course a governor must not hunt. If the governor, be it quick or slow in action, follows up too far the changes in the flow of water it will suddenly go beyond its proper regulating point and then hunt back and forth. As a matter of fact, the process which Mr. Steinmetz alluded to, the process of checking the action of the governor a a little before the work is completed, is applied systematically in at least one governor and it is the key of the situation. If a governor is free to hunt, you get bad regulation in nearly every case. The more nearly dead-beat the governor is the better the results. I don't think any relief is to be had by saying to yourself if I can't get one per cent. regulation and can get ten I will set my governor for ten. The more promptly the governor works and the better the arrangement of the hydraulic plant with respect to promptness in bringing the water pressure down, the better net result will be got on the whole. If you are working with a governor which is prone to hunt, which gives bad results—too much promptness is not desirable, but that particular governor is one it should be our object to suppress. As a matter of fact the railway plants which are driven by water are capable of giving substantially the same regulation as given by the governor of an ordinary engine; better results than with some Corliss engines. When it comes to dealing with high heads where water is wasted, the problem assumes a different form, but after all it is governed by the same considerations; you must follow out the fluctuations by

the swinging of the nozzles on the buckets and there you are liable to encounter hunting unless you are very careful.

It is, however, a more difficult problem in spite of the enormous water-velocity. As regards the matter of fly-wheels, I am particularly glad to have Dr. Garratt bring a few figures before us regarding the utter uselessness of fly-wheels in many cases. There are many cases in which you can store power, but I find advantageous cases are comparatively few. A little fly-wheel capacity is all right of course, but as to putting on fifteen or twenty tons of metal and the bearings to support them, simply for the purpose of enabling you to use bad hydraulic designs and bad regulating governors, it is to my mind a waste of good material and money. And that is continually done. As I go around through the electric plants driven by water-wheels I am bound to say there is more bad design in regard to the hydraulic plant, than good design. These facts that Dr. Garratt exhibits regarding the relation of hydraulic design to the possibility of governing are not generally understood, and the feeling generally is: "Well this is a pretty good hydraulic plant and we have got what we think is a pretty good governor, if it doesn't work well, put on a fly-wheel." And the worse the design the bigger the fly-wheel.

The more directly you can get the water at the wheel the more quickly you can work your governor gates, the better generally the net result will be, and as regards the matter of quickness, I think the figures shown ought to convey to us a lesson. I should suppose off-hand that no human being in his sound senses would undertake to make an apparatus which required regulation with the maximum possible amount of over-balance. But over-balance seemed to be a virtue in the mind of the man that made that wheel. With respect to these high-head wheels I should like to throw out an inquiry into the air, merely to awaken the interest as to why we do not use in this country the impulse turbines. That type of wheel is almost unknown here. All the turbines we have with very few exceptions are pressure turbines such as have been shown on the screen. The impulse turbine is comparatively easy to govern and it does save water. Why in the world that form of wheel is not used in this country, particularly on the mid-heads where it gives a convenient combination of power and speed, I don't understand. On one or two occasions I have raised inquiry regarding these impulse turbines and I have regularly met the pleasing information that they are not to the obtained in this country except I think from one small concern on the Pacific coast. Abroad they are used very extensively and some firms make almost a specialty of the impulse type of turbine. I think this is a subject that ought to be looked up in the interest of an economic use of water.

Prof. Goldsborough:—There is an element of skill which enters into the economical handling of these plants which has a very marked bearing upon the success that at-

tends them. Our attention has been called to one or two plants during the discussion, in which regulation is secured to the perfect satisfaction of their directors and as long as these plants are operated and controlled by men who understand them I have no doubt that they will continue to give every satisfaction. There is nothing more pleasing than to learn that in the west we have such plants as the Cottonwood and the Pioneer, located some thirty miles distant from one another, operating in synchronism in what seems to be a perfectly satisfactory manner. I understand that the engineers in charge are even sanguine of being able to operate a two-phase plant in synchronism with the two three-phase plants, by converting the two-phase currents to three-phase through the medium of transformers. In connection with the Minneapolis plant, I am not sure that its regulation always comes up to the expectations of the designers. I have understood, for instance, that at times, when the skill used in controlling the plant is possibly not the best, the results are somewhat disastrous. In other words there is a surging between generators located in the same station, and this at times is so serious that it extends through to the city sub-generating-station and the distributing system and causes more or less prolonged interruption of the street railway traffic. It seems to me, then, that even though the water-wheel governor be of very fine design, very sensitive and perfectly capable of taking care of ordinary conditions, if through bad management of the electrical machinery uncalled for conditions are imposed upon the plant, oscillations may be set up which result in placing the water-wheel governor at a decided disadvantage. You will all agree that in plants of this character, a number of which I know of in the west; in the interests of economy, there should be the requisite skill employed by the owners to the end of having them properly controlled from day to day, instead of simply employing talent to put them in shape and then removing the brains and expecting the plants to operate in a satisfactory manner. Many of us know of such instances, but fortunately they are growing fewer every day.

Mr. C. W. Rice:—Professor Goldsborough speaks of an interesting experiment that will probably be made on the plants in Utah, the Utah Power Co., the Pioneer and the Big Cottonwood. Each of these plants have very long pipes leading from the reservoirs to the wheels. Therefore they correspond to the cut, Figure No. 2. The pipe at the Pioneer plant is 6 feet in diameter and considerably over a thousand feet long. It has relief valves on the pipe near the water power station. There they have the impulse type of wheel. The Utah Co. and the Big Cottonwood have the Pelton wheel, the latter company employing the deflecting nozzle and the Utah Co. employing the shaded nozzle. They have a fly-wheel in the Utah Co.'s plant, so it will be interesting to see these three stations, considerably over thirty miles apart, operating synchronously.

MR. H. WARD LEONARD: A great many plants may have the necessity of a certain amount of steam in conjunction with them. Sometimes for heating purposes, sometimes as an auxiliary to the water power, and in that connection I can say that a good many years ago, between 1883 and 1889, I installed a great many plants where water power was in use and where a certain amount of steam was used as an auxiliary. As a means of overcoming this trouble of the governor, which has been discussed, I resorted to keeping the steam engines in operation, driving upon the same shaft as the water-wheels, and the cut-off of the engine governor was kept so adjusted that the steam consumption was practically that of friction load. The gates of the water-wheel were operated by hand, and the governor of the steam engine supplied the governor for the entire equipment. In case of a sudden load the engine would instantly assume the additional work required, and in case the load was thrown off, the engine would act as a brake on the system. And in places where during the winter months heating the station is required, you practically use no more steam than would be needed for heating.

MR. W. J. HAMMER:—In connection with this subject I think it would be interesting to hear of an experiment tried in 1888 in Florida, this being I believe the first experiment made in using water flowing direct from an artesian well for power purposes. I had the pleasure in connection with Mr. John Kennish of putting in a hydraulic plant in which a turbine was placed directly over an artesian well and which drove a belt-driven dynamo. There was no governor whatsoever placed on the turbine and the power was so steady that the candle-power of the incandescent lamps scarcely varied in the slightest degree, and while this was but a small plant supplying as I recollect it, 88 16-C. P. lamps, it had some interesting features. The entire wiring system of the hotel which supplied about 8,000 16-C. P. lamps was connected to this dynamo at times, and as this hotel was not supplied with any gas or other illuminant, during the following summer when the hotel was practically closed up, and in the hands of watchmen and caretakers, lamps could be turned on anywhere in this entire system and supplied from this water power plant. The plant was also used for supplying a large garden fête held in the grounds of the Ponce de Leon hotel shortly after its erection. I understand there is a plant working quite successfully in Florida supplied with power taken directly from artesian wells and there is one in the west. But the experiment I refer to was I believe the first one ever tried in this direction and it certainly worked with remarkable success, though at the time it was installed it was stated to be an impossibility by various engineers whose opinions had been asked. Those who are familiar with this section of Florida know that any amount of water under considerable head is encountered in drilling ar-

tesian wells. Geologists claim that this water has its source a thousand miles or more away. I don't think this little plant has ever been referred to in public print, and I thought it would possibly be of interest to bring it up at this point.

[COMMUNICATED AFTER ADJOURNMENT BY S. L. G. KNOX.]

Dr. Garratt's paper is an excellent presentation of the subject of water-wheel speed regulation, but there are one or two points on which I would take exception to the author's deductions.

In formula (13) the expression $V = 8.025 \sqrt{H}$ is given as representing the velocity with which water should enter the wheel. In the next paragraph reference is made to water friction as the only factor modifying the above. Agreeing that this factor would not notably affect results of calculations, I consider the statement misleading. Only in case the turbine under consideration were an impulse wheel would the above formula be even approximately correct. As there are few impulse wheels built in this country except Pelton wheels, and as the whole paper evidently refers to the ordinary turbine plant for generating electric power—almost invariably reaction turbines—it would seem that deductions based on conditions non-existent in the type of wheels used in American plants would be misleading. In the ordinary American reaction turbine, the velocity of the water would be much less than the speed given by the above formula, and this difference, carried through the calculations, would be found to profoundly influence the results obtained.

But even assuming that the above point need not be considered, or that impulse wheels, in which the water *does* leave the guides at approximately spouting velocity, are under consideration, the subsequent reasoning seems to be incorrect. Following the author's calculations on pages 374 and 375, we would be forced to conclude that the time required for the long column of water to get up sufficient speed to supply any new demand from the wheel for more power would be the time required for the same column of water to get up spouting velocity from a state of rest if the end of the feeder were open. That is, if the water in the pipe were flowing at say two feet a second, and a sudden opening of the wheel gate called for a supply of water such that a speed of three feet per second in the main feeder would be necessary, it would take, in the given instance, 23.3 seconds for this new velocity to be attained. Now in no case, except that of a sudden change from no load to full load, would anything like 23 seconds be required for the column to get up the needed velocity. As specifications for the governing of water power plants rarely call for close regulation for a change of more than half load, the time required to accelerate the column in case of a change of full load need scarcely be considered, and in

any event should not be considered as representing time required for *any* change.

Let us take a case in which it is desired to go from no load to half load instantly, and determine the time required before the water can supply the required energy. For purposes of comparison, let us take the same data as that given in the paper, for the wheel with 300 feet of feeder. In the first place, no question of regulation enters in unless the wheel is already running —that is, the wheel must be supposed to be revolving at normal speed, but only under friction load, when the sudden demand for power comes upon it. It is not likely that the friction load of wheels, shafts and generator, besides stuffing box friction, will amount to less than 8 per cent. of the full load. We must also remember that when the wheel is being called upon for only 8 per cent. of its power it is invariably working at a very low efficiency—certainly not over 25%. That would mean that the water passing through the wheel is four times 8%, or 32%, of that theoretically required to run wheel at full load. As the full load efficiency will be say 80%, the water required at full load will be 125% of the theoretical. At 8% load, therefore, the wheel will be taking $32/125=25\frac{1}{2}\%$ of the water required at full load. Assuming half load efficiency to be 65%—the water required would be 61% of full load water consumption.

We therefore have the following conditions. Water is flowing through the wheel to the amount of 25% of that required to give full power, and a sudden demand is made for 61% of the same amount. Let us assume, as does the author of the paper, that the water enters the wheel at spouting velocity. The gate now opens, and, the feeder being unable to instantly supply more water, the 25% of normal flows through an opening larger in the proportion of $\frac{61}{25}$ than that through which it flowed when it had spouting velocity. It hence immediately takes a velocity $=\frac{25}{61}$ of spouting velocity, for it certainly will fill all the opening presented by the gate. We therefore, in the case of half load going on, have instantly the condition of water flowing through the wheel at $\frac{25}{61}$ of spouting velocity, and hence only the difference, or $\frac{36}{61}$ of spouting velocity has to be given to the water by the action of gravity on the water in the flume. Taking 23.3 seconds as the time necessary to give full spouting velocity $\frac{23.3 \times 36}{61} = 14$ seconds, would be the time needed. This is very much less than the 23.3 seconds that would be needed if the methods of calculation given by Dr. Garratt were followed.

The preceding argument assumes that the gate is quickly opened to the exact place required for half power, and left there. As a matter of fact, however, a modern water-wheel governor, under the above conditions, would open the gate as far as it would go, and later close it. We would then have a somewhat

different condition. The water flowing when load came on would drop to $25\frac{1}{2}\%$ of spouting velocity, for gate would open to $100/25\frac{1}{2}$ times its original amount.

As the normal speed of the turbine would be only about 50% of the speed at which it would run with gate wide open and no load on the wheel, it is evident that the large volume of water which would flow with gate wide open would not have to flow at spouting velocity in order to give the same power to the wheel which 61% of the same cross sectional area of water would give when flowing at spouting velocity. That is to say, with gate wide open, wheel would give half normal power at normal speed under considerably less than normal head, the wheel of course in this case running at more than 50% of the free speed corresponding to the lower head and hence at less than best efficiency. We can assume that under conditions outlined above, water would not have to attain a velocity more than 70% of normal spouting, to enable wheel to furnish 50% of normal power.

Before being able to supply the one-half of normal power required, therefore, the water in the flume would, under the action of gravity, have to accelerate from $\frac{25\frac{1}{2}}{100}$ to $\frac{70}{100} = \frac{44\frac{1}{2}}{100}$ of spouting velocity, requiring $\frac{44\frac{1}{2}}{100}$ of $23.3 = 10.4$ seconds, or less than one-half time deduced by methods given in the paper.

It can easily be shown that the change from no load to half load is a much more severe condition than from half load to full load. In the latter case we have $\frac{61}{100}$ water flowing, and suddenly open gate to $\frac{100}{100}$, thus reducing velocity to $\frac{61}{100}$ of spouting. We thus have only to accelerate water $\frac{39}{100}$ of spouting velocity requiring $\frac{23.3 \times 39}{100} = 9.1$ seconds. As, however, most modern turbine installations have some margin of power in the wheels, the governor will in the case of full power demand, open the gate wider than is required to sustain the power, and the time of acceleration will be correspondingly shortened, as was shown in the case of half-power.

Had the usual case of reaction wheels been considered, where the water never attains, normally, anything like spouting velocity in entering the wheels, the time in seconds necessary for the feeder water to accelerate would have been shortened still more—say to two-thirds of the values deduced—6 seconds, as against 23 in the paper. These values, we also believe, will much more nearly coincide with experience than those deduced in the paper. Plants which by the methods of the paper would figure out even more than the one given, are by no means uncommon, yet the insurmountable difficulties of governing, such as the necessity of finding some source of stored power other than the water to keep wheels up to speed for 23 seconds are not met with, for the wheels *do* govern under changes of 50% load, and that with fly-wheels not carrying sufficient energy to tide over more than a very few seconds without losing more than the allowable speed.

The author of the paper also refers to the use of stand pipes, and to the lack of sufficient practical experience to determine the least diameter which will result in any desired degree of speed regulation.

I am of opinion that this matter of stand pipes is subject to calculation, and, having recently been over the ground in an exceedingly interesting case would be glad to discuss the matter with some detail. The subject is too large to attempt here, and will be taken up later.

Dayton, O., Sept. 11, 1899.

THE CHAIRMAN: Is there any further discussion upon the paper? If not, we will proceed to the next paper upon the programme which is "The Protection of Secondary Circuits from Fire Risks," by Dr. Hutchinson.

Dr. Hutchinson read the following paper:

A paper presented at the Sixteenth General Meeting of the American Institute of Electrical Engineers, Boston, June 27th, 1899, President Kennelly in the Chair.

THE PROTECTION OF SECONDARY CIRCUITS FROM FIRE RISKS.

BY CARY T. HUTCHINSON.

The best protection of secondary circuits from the dangerous consequences of an abnormal potential in these circuits, has long been the subject of discussion. In the early days when the house-to-house transformer system was general, many fires were caused by the failure of the insulation between the primary and secondary coils of transformers; this was then the chief cause of such accidents. No secondary distributing networks were then used, and consequently fires following a failure of insulation were confined to the circuits from the single transformer; it was unusual for a wide-spread fire to occur, and public attention was not as strongly directed to the matter as it has been of late.

In the last few years the use of alternating current systems has increased greatly; individual transformer systems have been replaced in many places by the use of "banked" or "grouped" transformers, with secondaries feeding a low-pressure distributing network. Such systems are now in operation in many places in the country, and their number is increasing. The secondary distributing networks may be of two, three, or more wires, the latter for two or three-phase systems. The secondary circuits in all such systems are directly liable to the incursion of the high primary pressure through the failure of the insulation at some point.

In addition to alternating current systems, there is another class of distributing systems subject to the same dangers—systems in which transformation is made from high to low pressure

alternating current, and thence by means of synchronous converters to low-pressure direct current for distribution. The use of such systems is growing rapidly; many of the Edison illuminating companies are already employing it, and it is a safe prediction that all the large companies will be obliged to adopt methods of this character in the near future.

Such a system has precisely the same conditions of insulation between the low-pressure direct current distributing mains, and the high-pressure alternating current feeders, as a plain alternating current system, since the low-pressure side of the alternating current supply is connected metallically to the armature of the synchronous converter which feeds the low-pressure direct current distributing system. In a word, there is only one insulation between high-pressure alternating current feeders and the low-pressure direct current network; hence such a system is liable to precisely the same risks as is the straight alternating current system.

There are a number of ways in which the high-pressure alternating potential can get to the secondary system. The most obvious is the failure of the insulation between the primary and secondary coils of the transformer; another is the contact of the high-pressure feeder and the low-pressure distributing main which may run on the same pole line, or in the same conduits underground. Wires that in ordinary circumstances seem to be secured beyond the possibility of contact may be brought into contact through unusual conditions, as in a heavy storm, or by foreign wires falling across them.

The effect of the failure of insulation, however caused, depends upon the condition of the secondary system. A brief statement of the various possible consequences may help to make the matter clear.

Any circuit, overhead or underground, carrying alternating currents, is a condenser, of which the capacity depends upon the point of view. In an overhead circuit, there is a certain capacity between the two wires, considered perfectly insulated, each as the plate of a condenser; there is also the capacity of each of these wires referred to earth, each wire being regarded as one plate of a condenser, and the earth as the other plate. The capacity in the first case fixes the difference of potential between the two wires for a given charge, or conversely for a given difference of potential between the wires fixes the charge.

The capacity in the second case—that is, regarding the earth as one plate of the condenser, fixes the potential of the wire above or below that of the earth for a given charge, or conversely. The capacity in these two cases need not have the same numerical value.

The same general considerations hold in the case of underground conductors; there is the capacity between wires determining the difference of potential between the wires, and the capacity of each wire and earth, determining the difference of potential between that wire and earth. The difference of potential between wires of a circuit transmitting energy is fixed, and the capacity is determined by the dimensions of the circuit, hence the charging current is fixed. This charging current is the current on the system when no energy is transmitted and there is no leakage.

Calling V_1 and V_2 the potentials above and below the earth respectively of the two wires, and C_1 and C_2 their capacities, the equation

$$\frac{V_1}{V_2} = \frac{C_2}{C_1}$$

will hold in all cases. If one wire is connected to ground, that is, if capacity C_1 becomes infinite, the potential V_1 becomes zero. Under ordinary circumstances, the capacities of the two wires are substantially the same, and the potentials, so far as determined by the capacities, are equal and of opposite sign with respect to the earth.

Leakage over the insulators to earth has a similar effect, tending to fix a relation between the potentials of the two wires and the earth; that is, it tends to maintain the potential of the two wires at a certain value above or below the earth, but in no way affecting the difference of potential between the two wires.

Calling the conductance of the two leakage paths to ground G_1 and G_2 the equation

$$\frac{V_1}{V_2} = \frac{G_2}{G_1}$$

holds, and if G_1 is made infinite, or one side is grounded, the potential of that side becomes equal to the potential of earth. If the conductance of the leakage paths on the two sides of the circuit

is the same, the potentials tend to become equal and opposite with respect to the earth.

The resultant effect of leakage currents and of the static capacity of the overhead system tends to cause the potential of the two wires to become more or less approximately equal and of opposite sign with respect to the earth when the circuits are symmetrical and insulated. In a circuit having a difference of potential of 2000 volts, the difference of potential between either wire and the earth is 1000.

The primary circuit then forms a condenser; any insulated conducting body in contact with either of the primary conductors, becomes a part of that conductor, and therefore part of one plate of the condenser, and at once acquires the potential of the wire with which it is in contact; that is, if an insulated secondary system is by any means brought in contact with an insulated primary system in which the potential difference is 2000 volts, this secondary system at once acquires a potential of 1000 volts above the earth. If the secondary system in addition has an electromotive force acting in its own circuit, then the difference of potential between this secondary circuit and the ground is increased or diminished by the voltage of its own circuit; in the extreme case, a difference of potential of 1000 volts plus the voltage of the secondary circuit, (say 100 volts) would exist, or, in all, 1100 volts between one side of the secondary circuit and ground; between the other side and ground the difference of potential would be 1000 volts. It is important to note that this difference of potential exists when the primary circuit is insulated. While this is true, it is also true that no current other than the charging and leakage current of the system can pass through the secondary system unless the primary system is grounded on the side opposite to that making contact with the secondary system. The charging current of the condenser will be practically inappreciable in all cases. For instance, at a frequency of 60 cycles per second, with a primary pressure of 2000 volts, the charging current is only three-fourths of an ampere for each microfarad capacity of the primary system. As the capacity of the primary system will probably be a fraction of a microfarad, it is clear that the passage of this current through the secondary system cannot possibly be the direct cause of danger.

The danger then lies, not in the application of an abnormal

pressure to a well insulated secondary system, but in such application to a secondary system where the insulation is too weak to stand the stress brought upon it. In ordinary house wiring systems designed for, say, 110 volts, the application of 1000 volts may or may not break down the insulation from ground, depending upon the care with which the work was done and the goodness of the materials used. If the insulation of the secondary system from ground breaks at only one point, and if the break is of such a character as to dead ground the secondary, then the abnormal pressure is at once relieved; the maximum potential above the earth that can exist on the secondary system as soon as this ground is formed, is the voltage of the secondary system; the moment the ground is formed, the danger is removed,—abnormal current cannot flow and consequently no fire can begin.

Assume, however, that the insulation of the secondary system is broken down at two or more points on opposite sides. In this case, a short-circuit is formed of resistance varying between zero and some higher value. The electromotive force acting in the secondary circuit, either alternating or direct, sends current around this short-circuit, in amount depending upon the resistance of the short-circuit. The current continues to flow until the grounds are entirely removed, or until the circuit is isolated, by fire or otherwise, from the source of supply. This abnormal current flowing around the short-circuit causes the fires; at every point where the current flows to ground, more or less energy is liberated in the form of heat, and fires will occur if local circumstances are favorable. The application of an abnormal pressure to the secondary system, in all probability will break down the insulation of the secondary system at several places, and these places will be distributed between two sides of the secondary system, as a matter of probability.

If the primary circuit is grounded on one side, and contact is made between the grounded side and the secondary, no harmful consequences can follow. If contact, however, is made between the insulated side and the secondary system, the full difference of potential of the primary will exist between the secondary and the ground,—that is, twice the difference of potential that existed in the case of the insulated primary. To all intents and purposes, the difference in effects caused by grounding one side of the primary circuit, will not be material. One-half of the

difference of potential of the primary circuit will probably be as effective as the whole.

Although alternating current electric lighting systems have been in use in this country for a number of years, no definite practice has been followed for the protection of secondary circuits. The chief improvements that have been made in the art, have been in the character of the insulation between the primary and secondary coils of the transformer. After careful investigation as to the present practice here, I am in a position to say that in practically no case is any device regularly used to protect secondary circuits against abnormal pressure. A number of station managers have attempted to use, and in a few cases have used, devices such as I am about to describe, for a short time. The outcome of all such work has been, in general, unsatisfactory. The need of some effective method for protecting secondary circuits is well recognized, yet there is at present probably no device for the purpose that is thoroughly trustworthy and efficient in all circumstances.

The means that have been employed for this object, may be classified generally under three heads,—

1st.–Devices intended to ground, short-circuit or open-circuit the secondary circuit when subjected to an abnormal difference of potential.

2nd.–Grounded metallic shields interposed between the primary and secondary coils of the transformer.

3rd.–Permanent grounding of the secondary system.

Under the first class are the Cardew earthing device, in which a flexible metal strip is attracted to a fixed ground plate by the action of the abnormal potential, thus grounding one or both sides of the system; the Thomson film cut-out, in which an insulating film designed to withstand the working pressure, but to puncture at an abnormal pressure, is connected on one or both sides of the circuit between two plates, one connected to the conductor, the other to earth; the Stanley automatic circuit breaker, in which a flexible metal plate is attracted by the abnormal pressure to a fixed plate, thereby closing a local circuit through a solenoid, which acts to open the main switch on the secondary circuit; and others of similar character.

These devices all have one fundamental weakness,—they do not prevent the existence of the abnormal potential, but merely aim to remove it quickly; they all require time to act,—the

secondary system acquires the abnormal potential at all points at the same instant, and there is no certainty that the insulation of the circuit, say at a combination fixture, may not give way before the device acts. Further, those that act to ground and to short-circuit the secondary, depend upon the blowing of fuses before the cause of danger is removed; those that disconnect are subject to all the criticisms brought against high-voltage quick-acting switches,—in particular, the maintenance of the arc.

I believe that all devices under this class are, at best, temporary makeshifts.

The grounded shield is obnoxious to various criticisms,—it is not effectual with a cross outside of the transformer, and therefore is of no value in many cases; it must be heavy enough to dissipate the energy of the short-circuited primary quickly; otherwise it melts and is itself the cause of a fire; it degrades the transformer, tending to cause unsatisfactory service, particularly in the regulation.

The third method, grounding the secondary permanently, is the only sure way to prevent the potential above earth of the secondary system rising above the voltage of the circuit. With a system grounded on one side, the maximum difference of potential that can exist between any point of this system and earth under any circumstances, is the voltage of that circuit. No cross nor any failure of insulation of the primary or secondary circuits, can raise the difference of potential between the secondary circuit and ground above this. That side of a primary circuit touching a grounded secondary circuit, at once acquires the potential of the ground or a potential differing from that of the ground by the voltage of the secondary circuit. The grounding of the secondary circuit thus absolutely ensures the safety of the circuit as regards abnormal pressures; it makes permanent the condition that the various protective devices seek to establish,—devices that may or may not work, depending on many conditions.

It would seem that a remedy as simple as this,—one generally applicable,—would have been applied in all cases; but the fact is that it has attained a limited use only. The reason for this state of affairs is the refusal of the Board of Fire Underwriters to authorize the practice of grounding any part of a circuit carrying current. The underwriters take the position that to ground one side of a circuit brings about an increased liability to

fire, because the full voltage of the circuit continually acts upon the insulation of the circuit, instead of one-half of this voltage, as in an insulated system, and because one accidental ground on the insulated side may cause a fire. The danger with grounded circuit is said to be increased by the fact that the full voltage of the circuit instead of one-half, acts upon the insulation of the insulated side. This argument implies two things: first, that insulation good enough to withstand half the voltage of the circuit is not good enough to withstand the full voltage of the circuit; or, that danger would be materially increased by having the full voltage of the circuit on the insulation, instead of one-half. This is contradicted by the fact that the underwriters' rules class all circuits having a difference of potential of 300 volts or less as low potential, to which the same rule applies. That is, in the case of an insulated 110-volt circuit, which means 55 volts on the insulation of each side, the same rules hold as in the case of 220 volt circuits, with 110 volts on the insulation of each side.

If the 110-volt circuit had one side grounded, there would then be 110 volts on the insulation of the ungrounded side. It is true that the classification ostensibly permits only 150 volts on the insulation of one side of the circuit; hence, if one side of a 220-volt circuit is grounded, the stress brought upon the insulation is greater than is seemingly permitted; but as a matter of fact, the factor of safety in work of this kind is much greater than called for by this slight difference. There is no doubt that a wiring system properly installed in accordance with the rules laid down by the underwriters, is perfectly safe with 300 volts on the insulation on one side, and practically speaking, it is just as safe with 300 as with 150 volts; if the former would cause trouble so would the latter. I have assumed that one conductor of a two-wire system is grounded. If the middle point of the secondary coil of transformer be grounded instead of one wire, then the stress on the insulation is in all cases one-half of the voltage of the circuit, precisely as in the case of the grounding of the neutral of a three-wire system, mentioned below.

The main objection brought against grounding is, however, not the increased stress brought to bear upon the insulation, but the fact that only one additional ground is required to establish conditions favoring a fire. The argument is, that the

simultaneous existence of two grounds on the opposite sides of the circuit is less probable than the occurrence of a single ground on the insulated side of a grounded circuit.

I do not consider these arguments strong for several reasons. In the first place, they imply that an indefinite condition as regards the insulation of the circuit is preferable to a clean-cut, definite condition. Circuits supposably insulated may or may not really be so, and as a matter of fact the full stress may be, and frequently is, on one side of the circuit; the very condition that the underwriters refuse to sanction is continually occurring without such sanction.

The Association of Edison Illuminating Companies has had a Committee on Grounding the Neutral since 1890. The recommendations of this Committee being based on extensive experience are entitled to great weight. Their recommendations have uniformly been that the greatest safety was assured by the practice of grounding the neutral. This is the practice of nearly all the large Edison companies, as is well known. In some cases, the companies have been forced to this position because they were not able to free the neutral from grounds; in other cases they have deliberately adopted this as the best remedy for many troubles due to operation, to dangers from fire, and to abnormal pressures.

This Committee has claimed at all times that grounding the neutral has the advantage of "Reduced fire risk, since a ground created inside a building will, if on the neutral conductor, be in no danger, while if on the outside conductor, it will probably fuse a safety catch, or do all the damage of which it is capable at once, and not remain inactive until the appearance of a subsequent ground on the opposite side of the system, at a time, perhaps, when no person may be at home."

"Also, that the electrical pressure capable of causing damage by reason of any ground established, either in tubes or in buildings, is limited to 120 volts, whereas the active pressure might otherwise be 240 volts; and for overhead circuits greater immunity from lightning."

The disadvantages reported by this Committee are possible troubles in operation, particularly in regulation and excessive registration on the meters, but no increased risks are foreseen. The Committee has made its reports in face of the fact that the underwriters have uniformly refused to countenance the practice.

It is a notorious fact that the systems in nearly all of the large

cities, particularly the Edison systems, are grounded, the neutrals in most cases being permanently grounded at the junction boxes. It is equally well known that in several of the large alternating current distributing systems, the neutral wires are grounded. The authorities of the Board of Underwriters certainly should, and probably do, know these facts. To keep rules in print prohibiting such practice under the circumstances, must weaken their authority, and lessen the respect for all their rules.

The rule against grounding the circuit is not the only one that is continually violated, and by inference with the knowledge of the Board of Underwriters. The second is that which calls for double insulation between primary circuits carrying 6,000 volts or more, and secondary house-wiring systems. I protested against this rule when it was promulgated, citing cases where it was violated at that time, and saying that it would without doubt continue to be violated. It is violated in every large city employing alternating current distribution with synchronous converters feeding a direct-current distributing system, as for instance, in Brooklyn, New York and Boston, not to go further. Such a rule is vicious in its tendences, and should unquestionably be modified.

In this discussion alternating and direct-current systems are considered subject to the same risks; this is the case now in the large cities where synchronous converters are used; but in any event, the arguments outlined will apply to any system subject to an abnormal potential, whatever may be the cause.

This is a matter that concerns every electrical manufacturing company and engineer in the country; this INSTITUTE has recently taken part in the formation and modification of rules governing electric installations and has endorsed the National Electrical Code. Therefore, it is entirely in the province of this body to make recommendations as forcibly as it may see fit to the Board of Underwriters. I therefore offer the following resolution:

Resolved, that the AMERICAN INSTITUTE OF ELECTRICAL ENGINEERS favors a rule permitting the grounding of one wire of every low potential consumption system.

Resolved, that the Committee of the AMERICAN INSTITUTE OF ELECTRICAL ENGINEERS on the National Electrical Code is hereby requested to confer with the Electrical Committee of the *Underwriters' National Electric Association* in relation to recommending to the *National Board of Fire Underwriters* the passage of a rule permitting or requiring the permanent grounding of one wire of such systems, under suitable restrictions.

Resolved, that they also confer with the same committee in regard to recommending to the National Board of Fire Underwriters some modification of Rule 39 of the Code in relation to the installation of secondary wires when the primary wires carry a current of over 3500 volts potential.

DISCUSSION.

PROF. ELIHU THOMSON:—I think it proper I should lead off in this discussion. In this connection I wish to offer a moderate criticism as to the use of my name in regard only to the film cut-out. The fact is my name should be used if at all on the three devices together, as there appear in patents of the United States back about fifteen years ago, the grounded secondary and grounded shield, and the devices which respond to high potential, and work cut-offs. These arose from a feeling I had that no system could be considered fit for use, unless it had some such device. In fact, if the files of correspondence in our records could be looked up it would be found that upon every occasion that arose I took the opportunity to insist that alternating systems, to be considered safe, must be protected in some such way, and I felt that alternating currents should not be put into service until we had got some such safety device. Just as soon as we got those devices we were ready to do business. Now, the actual state of the case is this, that the wiring in my former house in Lynn, I think the plant was installed about 1887, had its secondary grounded. I grounded on gas and water pipes and preferred that arrangement to any other. But there were kickers as there always are against such simple proposals and as a compromise we afterward did not ground the secondary completely, but put a film between the secondary and the ground. That was the origin of the film cut-out. We put the film on both legs of the secondary, and of course a primary connection was supposed to break it down and give us protection when needed.

I will say in my own plant I also used a film after the first grounding in the following way. I felt that something might occur to interrupt the connection with the leg of the secondary on which the ground was, and therefore to be perfectly safe about it I put a film between that leg and the other so that if anything interrupted the ground side, the film would break down and ground the other side. This is all of course ancient history, and I have been doing my best in correspondence and in papers before the *National Electric Light Association* and upon similar occasions to enforce just what is put forward so nicely in the paper before you. I endorse everything that is said, and I hope some action will be taken by a body so influential as this, toward getting some such thing adopted.

MR. C. M. GODDARD:—Mr. President, I did not understand

that Prof. Thomson formally seconded Dr. Hutchinson's resolution. I should like to second the resolution and for several reasons. Not, however, because the underwriters are fully convinced as yet, that one of their rules, almost as unchangeable as the laws of the Medes and Persians, that no circuit should be permanently grounded, has been wrong all the time, I am not convinced of that fact, but because we are delighted to have the INSTITUTE take up any subject in relation to our rules and try and help us to arrive at a right solution. I think in the past the INSTITUTE has been almost too much afraid to put itself on record as favoring or opposing any particular rule. Individual members have frequently spoken (sometimes possibly in disrespect) of the underwriters' rules *in general*, but to come out fairly and frankly and try and help us to improve the rules has been a course which they have not taken so freely until through the efforts of the National Conference we were brought more closely together, and found we were not on either side quite such dreadful creatures as we had supposed, and that we were both trying so far as we could to work toward the same end. The station manager is just as much interested from a commercial standpoint, that his current shall not set fire, as the underwriters are.

I think it very probable that this grounding of the secondary may be the best solution, but the underwriters are always conservative in such matters. We had the various earthing devices. I have seen the cut-out of which Prof. Thomson speaks, and I think I have heard it spoken of by station managers even more disrespectfully than the rules. These devices have given trouble, they were steps towards something which we were trying to accomplish, but they were not perfect solutions. We have found many of these film cut-outs supplied with pieces of straw paper and writing paper and even blotting paper, one time we found two thicknesses of blotting paper, and should not have been surprised to find asbestos board used.

But the great point in favor of grounding a circuit permanently, is that it would be thoroughly and properly grounded, and as Dr. Hutchinson says you then know what you have. It is in my mind largely a question of choice between two evils. I don't think that anybody will deny that the grounding of one side does to a certain extent increase the fire risk, especially where we find combination fixtures, and the wires run in proximity to gas pipes, and in a great many of our older installations I should be afraid to ground either side permanently until we had made careful tests. You are all familiar with the old style of insulating joints, lots of them in existence to-day, and underwriters' wire, wooden cleats, no insulating tubes where the wires pass through the building. When you came to a brick or plaster wall, eight or ten years ago, there was a piece of soft rubber tubing there; what it is now you can all imagine. The underwriters are conservative, but they are de-

lighted to have the INSTITUTE help them, and if these resolutions pass, and the Committee on Code of the INSTITUTE will take this subject up they will find that the Electrical Committee of our Underwriters' Association will take it up just as carefully, and try to be reasonable, and I have very little doubt but what we shall arrive at a solution satisfactory to both sides. The same way with the rule in regard to double transformation with extra high potential. If you undertake to carry 10,000 volts through the streets of Boston we (the underwriters) can't stop it, but we say there must be a double transformation before it is put into use in insured buildings, and the chances are that this will largely relieve the streets of these extra high potential wires through the use of transformer stations in the outskirts of the city. The presence of high potential wires in city streets is certainly something that firemen very strongly object to at the time of a fire, and if the underwriters did not impose any restrictions, the city authorities probably would. We would be delighted to have you help us in making our rules. We modified this rule last year at the request of the INSTITUTE, and we will certainly modify it further if you will only come to us and show us that you are right, for we have a great deal of respect for the opinions of the INSTITUTE. We now have six months to work on these questions before the next meeting of the Electrical Committee of the Underwriters' National Electric Association, and I have not the slightest doubt that if your Committee will do their share of the work we will arrive at a solution that will be satisfactory all round, and I hope the INSTITUTE every time it finds a rule criticised will get some member to write a paper and give us the expression of their opinion. And I most heartily second Dr. Hutchinson's resolutions.

PROF. GOLDSBOROUGH:—After the opinions that have been expressed in favor of grounding the secondary, I hardly feel like saying anything in opposition, but I am very much interested in the subject and all my experience has tended to lead me to feel it is not best to ground the secondary. I do believe that grounding the secondary is much better than any other device that has been suggested, outside, possibly, of the shield. But I think the grounding of the secondary is a step in the wrong direction. It does not accord with present tendencies, nor with the rules that the INSTITUTE has adopted requiring very rigid tests of all machinery and defining these tests very carefully. In other words, if you ground the secondary you give people who are installing inferior equipments a loophole through which they can crawl. An electrical installation will not be any stronger than its weakest point, as in the case of any other installation of an engineering character, and I think what we should do would be to advise that after an installation has been made it be subjected to a two or three or four hour semi-short-circuited test, *i.e.*, a test of

several hour's duration with 50 to 100% more current flowing through the mains than they are designed for. In this way all the joints, wiring and connections will be subjected to a greater temperature rise than when in service. After this has been done, all of the short-circuit connections should be broken that have been put in, and the system should be connected on to a high pressure transformer through very light fuses. By increasing the voltage on the whole system until double the primary voltage has been reached, the system will be subjected to a sufficiently severe test. If the contractor has to put in a job with those conditions staring him in the face he will be careful about the details of the installation. Ordinary insulation installed as we do it to-day will stand such a test if it is carefully put in. The fires we have usually result from there being a weak point, some point where a workman was careless in putting material in place. In view of present method, I think any engineer in going over a large installation or even a small one, will be more than likely to find just such weak points.

I don't know but that this statement of my opinion on this matter may seem rather radical to some of the members of the Institute and not wholly warranted. It is a sort of departure. But if we demand that a transformer shall be built to stand a test at 10,000 volts it does not seem to me we should put in a very low insulation resistance in the secondary equipment. I don't refer to light insulation, but insulation installed in a careless way. Furthermore, I am quite sure that members of the Institute will bear me out in saying that the underwriters experience most of their troubles from not seeing that their rules are carried out. I have in mind an installation where I have requested them to send an inspector, and that installation has been in a year and a half without any attention on their part. They have taken my word for it that it is all right. The building in which the installation was made is valued at possibly $20,000, and if there is a fire there of course their policies will hold.

I would like to say in conclusion that in experimenting, as far as the element of personal care in such matters is a factor I think we all formulate a set of rules for ourselves as we gradually become accustomed to high-voltage apparatus. We learn automatically to protect ourselves. If I am using voltages as high as 10,000 volts I don't want anything grounded. I would like rather to have the transformer and generator and apparatus insulated, and personally, I feel safer under those conditions.

Mr. Steinmetz:—I beg to disagree herein with Prof. Goldsborough. Regarding the proposed test of operating the lines with 50 to 100% more current, I do not see any object, since the mains should be protected by fuses against overheating, and it is the business of the underwriters to see that this is done.

Operating at twice the voltage does not seem to me to be quite sufficient protection either.

PROF. GOLDSBOROUGH:—I mean twice the high-tension voltage.

MR. STEINMETZ:—Twice the high-tension voltage as a rule appears to me an unnecessarily severe test between the conductors, since a breakdown between the conductors short-circuits the secondary system and thereby blows the fuses. The real danger appears to me to lie in the insulation against grounds, and no specifications regarding this insulation appear sufficient if there are no means available for testing the insulation.

But if, as Dr. Hutchinson proposes, it would be made permissible to ground the secondary circuit, or as I should rather like to see it, mandatory, then it would be easy to test the dielectric strength of the secondary system against ground, and such a test, which can be made in a few seconds, could be prescribed before accepting an installation.

By opening the ground wire and inserting in the gap the high-tension coil of a small testing transformer of 1:10 ratio, with its low tension coils connected to the secondary mains, the whole secondary circuit is raised to a potential against ground equal to ten times the operating potential of the secondary circuit. As you see, the existence of a permanent ground would make such a test very easy indeed and feasible in a few seconds, so that the installation could even be re-tested from time to time. I need not say that I am very much in favor of Dr. Hutchinson's resolution.

There has been in the last few years a great deal of discussion as to whether grounding the secondary is safer regarding fire risk or not, and the majority of opinions seem to be strongly in favor of grounding.

Regarding danger to life, however, there never has been any doubt, and never can be, that the only absolute and perfect protection against danger to life in case of an accidental contact of the lighting circuit with a high-tension circuit of any description, is a permanent and absolute ground of the low-tension circuit.

I should certainly hesitate, when standing for instance on the damp floor of a cellar, to turn on an incandescent lamp when knowing that the only protection against certain death is the insulation of some unknown type of transformer which hangs somewhere on a pole, exposed to the weather for years. The film cutout as a protective device is certainly better than nothing, and there may be people who would enjoy getting into a 3,000-volt circuit if they know that a film cut-out will probably open the circuit quickly, but I myself should decline to do so. A further feature in direct current systems is, that an extended ground of the neutral offers the best protection against electrolytic action by restricting the path of the leakage currents from the unavoidable leaks on the outside wires.

Prof. Goldsborough :—I forgot in mentioning the test I advocate, to say that I also favor the test between the secondary mains and the ground. My idea is to have a test which will be analagous to the test to which the transformer itself is subjected. As regards the matter of using double current in making the test, that is simply for the purpose of heating and thereby weakening any point that may be faulty so that when the high voltage test is applied the fault will break down.

Dr. Bell :—I would like to call the attention of the Institute to the fact that it is not the initial condition of the circuit that makes trouble. Prof. Goldsborough says tests must be applied with the utmost rigor. Where they are running in adulterated rubber on us you cannot expect long life of insulation, and that is the trouble with any position whatever depending upon strict insulation tests at the initiation of a plant, be it a large plant or be it house wiring. Two or three years after the plant has been in service it is just as likely to be full of leaks as if it had been so in the first place. Test your circuit as thoroughly as you please to satisfy yourself that on this 27th day of June it is all right but ground it so that on the 27th of next June it will be safe even if the insulation is deterioriated.

One of the things that engineers forget is the danger from arc circuits. Those are generally run in a slipshod manner, the insulation may be hanging from them in strings, and as to the voltage, it is all very well for the underwriters to demand double transformation for anything over 3,500 volts, but how about the arc light circuits which are running anywhere from 2,000 to 5 or 6 or 7,000 volts over all sorts of overhead wires. The Edison circuits are in tenfold more danger from arc light circuits than they are from any breakdown between the primaries and secondaries of transformers on their own systems and it is in respect to all these contingencies that we must guide our practice. If we ground the secondaries we are compelled to be safe everywhere. The more thorough tests we put on prior to that the better. That matter will take care of itself. But once grounded you definitely limit the potential between the wire and the ground. And there is another thing in this connection which comes into practice in some of our high-tension long-distance plants. Supposing you were using a three phase transmission circuit as is generally the case in high-voltage plants. How about grounding the neutral point of the primary? How about grounding the neutral point of the distributing primary? By doing that, you very greatly reduce the tension between wire and ground, and consequently increase your safety all round. The only legitimate objection that can be brought against the grounding of secondaries and grounding of primaries in that way, is that objection which may be brought by the manufacturer on the ground that it is subjecting his machines to outrageous strains. But since the manufacturer is perfectly willing to take his medicine, and would prefer

to have the machines grounded, I think it is very far from the province of those of us who have nothing at stake in that matter to say "You shan't ground your secondaries because something that we do not understand may possibly cause trouble of a character we cannot predict in some wiring we know nothing about." And I can see from my own observation that the application of half the underwriters' rules in full rigidity would do more to secure safe wiring than the publishing of a volume of instructions and addenda thereto. I have seen houses wired within a thousand feet of the habitual residence of men whose business it was to inspect, so dangerously that I would not care to take electric light if I lived in them. It is the carrying out of a few simple rules to their legitimate conclusion that will give us safety. Once your circuits on the secondary side are grounded you know where to to look for trouble. You must keep up the insulation of the circuit with respect to ground and that can be done. Once that is done we are on comparatively safe ground. And in seconding again Dr. Hutchinson's resolution with respect to bringing this matter before the underwriters I would like to call the attention of the INSTITUTE to the fact that it is probably known to most of us that in making this provision for grounding neutral wires and grounding secondaries we are simply following out a line which they are following abroad to-day continuously. Not only is it permitted but it is required in the installation rules abroad, and I would like Mr. Steinmetz to go considerably forward, and not only make the grounding of the neutral permissive, but mandatory: grounded at some point which will protect the secondary system from the high-voltage current.

MR. JAMES I. AYER:—This discussion is agreeable to some of us. Some ten years ago, realizing the necessity for this protection I secured a compromise with the underwriters by having them permit me to construct and use circuit breakers with magnets of high resistance; these magnets were connected across the secondary mains and a connection to ground made between the two magnets, and in this way we grounded the secondaries. Anything over 400 or 500 volts coming in on the secondaries would pass sufficient current through either or both magnets to open the main line switch. The whole device was enclosed in a box so that it was impossible to close the switch when once opened, without removing the cover of the box that was closed with a seal. I got permission to use such a device as this but could not get permission to ground the secondary.

Some four years ago, Prof. Puffer, at a meeting of the INSTITUTE brought up this subject and strange to say there was no material discussion. He brought it up with fear and trembling and said he was going to ask for the consideration of a thing which would lead to much criticism, namely, the question of grounding secondaries of alternating circuits and particularly those operated from high-tension, long-distance transmission mains. The mem-

bers of the INSTITUTE at this meeting, four years ago, seemed to have no appreciation of the necessity of this or some similar protective method. To-day the necessity is not as great as it was ten years ago, nor even fifteen years ago when Prof. Thomson realized it, although at that time there were very few circuits to protect.

I desire to-day to add my testimony to others here, indicating the necessity of this action being taken because I think it is a part of the work of the INSTITUTE at its meetings to do just this sort of thing and I trust the resolution will get the full endorsement of all the members present.

There is one point in connection with all this, the detail of grounding and the detail of protection as Dr. Bell has mentioned is a thing to be looked after. Many methods have had to be abandoned in the past on account of the difficulty of securing safe and permanent grounds. That is an element which must be considered in determining any final resolutions in connection with it because I take it, it is necessary to prescribe some methods in detail as to how the work shall be carried out as well as to indicate generally that it should be done.

CAPT. WM. BROPHY :—I am somewhat familiar with this subject, having discussed it with Prof. Thomson several years ago. I did not agree with him at that time that it was a good plan to ground the secondary wires, for the reason that we did not have at that time the improved devices that we have to-day. We had then insulating joints that were such in name only. We had soft rubber tubing and various devices that have long since disappeared. Again I think that to the fact that this plan was opposed at that time, may be due the great improvements that have been made in transformers and better forms of insulation and translating devices generally. The only safe rule to follow in the transmission of electrical energy is to construct the circuits in the best possible manner, use the best form of insulation and the best devices that can be procured, in fact have every inch of the circuits as nearly perfect as they can be made. We now have transformers that are far superior to the earlier types, and which are very nearly perfect. With the great improvement in material and devices, I can see no great objection to this plan.

In New England there have been but two lives lost since the introduction of the alternating system, due to the breaking down of the insulation of transformers, one in Boston, the other in Woburn. There has been some criticism of the underwriters indulged in which I think is unjust. The station manager is apt to throw the burden that belongs to himself onto the shoulders of the underwriters' inspectors. He owes it to his company and to its patrons to see that the most approved form of electrical work is done, and the best material used.

He injures the business not only of his company but of every other one throughout the country when he countenances slipshod

methods of electrical construction. It is true that the manager is not always responsible for fires due to the failure of insulation and faulty construction, while we have that peculiar genius —the would-be contractor. Most of the contractors are reputable gentlemen who try to do what is right unless driven to do otherwise by irresponsible parties and unfair competition. Now the underwriters cannot undertake to supervise every installation that exists throughout the country as rigidly as they should do. It is too much to ask or expect of them. They have a right to depend largely on you and you should assist them; I mean those in the electric lighting business. They should put their shoulders to the wheel and do the greatest amount of that work, and not throw the entire burden on the underwriters and municipal inspection boards. As I have said before, I think the time has come when this plan of grounding the secondaries can be adopted, except in the case of some of the older installations the conditions of which we know so little to-day.

Ten days ago in this city we had a breakdown of a transformer in what is called a fire-proof building. In it were the old type of insulating joints which proved to be of little value; the current passed over them without difficulty and a fire occurred at every fixture. Had it been a frame building it would have been destroyed. The wires were run in paper conduits, on which time had laid a heavy hand, resulting in grounding the system, to which was due the failure of the transformer. It may be asked where were the fuses? If there is any one thing that is more unreliable than the ordinary fuse I have yet to see it. In this case the fuses failed to "fuse;" they were a first-rate fuse from one point of view, their melting point being exceedingly high and they did not give way and open the circuit; as heat resisters they proved a success.

The neutral wire has been grounded here in Boston for several years. Why shouldn't it be? You cannot keep a system as extensive as that of the Edison Electric Illuminating Company clear of grounds. While we can maintain a high standard of insulation in the interior of buildings, we find no serious trouble resulting from the grounding of the neutral wire. The true rule to follow, is to use the best possible insulation and do the highest class of work In the underground system of this city, which is limited to the section south of Dover street we can maintain a maximum of insulation, but with very few exceptions a portion of the circuits extend beyond the underground district, and at times in the overhead portion, there is absolutely no insulation, consequently the absolute resistance of the circuits is greatly reduced. Owing to this fact, the insulation of interior circuits should be, in fact must be, maintained at the highest point possible.

Prof. Puffer:—I can speak of this matter from three points of view: first, as the teacher on electrical engineering; second,

as a member of the INSTITUTE; third, as consulting Electrical Engineer of the Associated Factory Mutual Insurance Companies.

As the general tendency just now seems to be for some reason to attack the insurance interests for failure to require what less than a year ago was bitterly opposed by these same gentlemen, I will speak as an expert of the insurance companies. On taking up the matter of rules and regulations, I found that things were in a very bad shape, especially the alternating current installation.

In making up our minds what to do for rules, it seemed best to adhere to the existing rules at first, and while looking around for means of increasing the safety of transformer work I consulted about all of the electrical people I happened to know, and they were a great many, and I am glad to say that two of the members who have spoken here, Prof. Thomson and Mr. Steinmetz agreed thoroughly at that time that there was no known device, no known trick of engineering that they knew anything about which rendered secondary wiring safe except the grounding of the neutral of the secondary. But business matters were such that it didn't seem desirable for every one to take that view, yet I always found that even those men whose official views were against grounding transformers had a sort of sneaking impression that when the transformer was outside of their house it was going to be grounded, which I always considered as expressing their positive feeling that there was a decided danger.

When I brought up the plan of grounding the secondary, at a meeting of the INSTITUTE in New York a few years ago, I found that the temperature of the meeting was much below that of liquid air and the plan was then treated as vicious.

I want to go on record as stating what I believe to be the truth, that this grounding of the secondary has been held off for two years by the action of gentlemen in connection with electrical industries. I have attended the annual meetings of the insurance inspectors and I found two years ago, that it seemed as if we could adopt a rule requiring, under suitable conditions, a grounding of the neutral circuit, but it was prevented by the statements and efforts of certain electrical gentlemen who I presume believed what they said. Now, it is unfair to state that the majority there at that time were responsible for failure to permit the grounding of the secondary under suitable conditions, which was permissive according to our rules. At the Convention last December, action was deliberately prevented in substantially the same way, again relieving the insurance people. It is not fair for any man to turn around and say that this thing has been held off as long as it has purely by the insurance people themselves. It is not so.

There are however a number of things to bear carefully in mind in connection with this grounding of the neutral or middle point (as I prefer to call it) of the transformer itself. It

has been stated here by some gentlemen that the ground on the middle of the transformer secondary removed all possible danger. That is a mistake, unless the gentleman couples with it the fact that the transformer is provided with reliable fuses in the primary wires. For if it is not fused you can then get a drop through the impedance of the secondary that will give you a dangerous difference of potential between the parts of the secondary system and the earth.

Another thing in connection with this ground wire is that it should be sufficiently large to have a greater carrying capacity than either wire of the transformer itself. I think you will see from this consideration, that all such things as earthing devices become simply negligible, they disappear in smoke with the first short-circuit that happens to come.

In regard to grounding the secondaries of transformers there was one criticism brought up that led me to think that the gentleman had in mind the possibility of the ground being removed by the blowing of the fuse, leaving the transformer still in, and that there could be no installation test made of the wiring under such a state of affairs. If you ground the middle of the secondary, the simple removal of the ordinary prescribed fuse leaves your wire absolutely free for any test you desire and the ground is where it should be, back of all fuses, on the secondary side, and protected by the fuses of the primary side.

I want to call your attention to the fact that the presence of a large grounded system may in itself introduce a dangerous element from the fact that it as a whole becomes a conducting system for foreign systems, and I refer to the fact that a large grounded system may become a return for railway circuits to such an extent that the regulation of the two sides of a three-wire system will be found to be complete.

I would carry grounding to such an extent that I would compel the absolute grounding immediately at point of entrance into buildings of every system (except series arcs which ought not to be allowed in buildings) and including such things as water pipes and gas pipes. Not many hundred feet from where we are now there has been a serious case in which a building with no electric wires in it was set on fire by a current which came in over a water pipe and went out by a gas pipe. If these pipes were connected in the basement and therefore grounded at same point and that building had electric wires and the neutral were grounded, nothing would enter that building of a greater potential than that allowed by the rules, of 300 volts.

Mr. Steinmetz:—In connection with that most formidable and least tangible danger, the contractor who does improper wiring, I would call attention to the advantage of the grounded circuit in permitting a quick and simple test of the insulation strength.

It is true that the methods of insulation have been essen-

tially improved during the last year and as a minimum test of insulation in transformers now 10,000 volts is proposed. But nevertheless, a transformer installed to-day and tested for 10,000 volts may be broken down absolutely to-morrow by causes beyond your control and unavoidable, as a secondary lightning stroke.

The grounded shield is a fair protection also in the transformer, but to be perfectly safe it must hermetically enclose the secondary coil and all its leads, which is not well feasible, and must be perfectly grounded which is very difficult to accomplish at the place where transformers are usually located.

PROF. THOMSON:—On the point of the difficulty of making a ground I see that sometimes lightning makes a mistake in that particular. At Lynn a while ago it thought it had a good ground by striking the water pipe but it had to strike two or three houses and had to break about a dozen joints in water pipes to get away to earth.

PROF. GOLDSBOROUGH:—I think probably by taking the position I have in this discussion there has been brought out the fact that after all the difference between the ideas I have and those voiced by the other speakers is very slight. I think it has been very strongly brought out so far, that even though the secondary is grounded, as I am quite sure from the sentiment generally expressed it is going to be, we must insist upon good insulation of the house wiring. In opposing the ground I do so largely because I think it will lead to people feeling that, as they have a ground protection, they are safe anyway, and they will be more or less careless about the matter of insulation. In fact I know of a case in which weather-proof wire was used in interior wiring and no complaint has been made about it.

The old transformers which are now in use should not be subjected to the strain necessarily resulting from grounding the secondary. The plan which is suggested here might well be made to apply to future installations. We can't, unless radical steps are taken, make existing lighting plants throw out their old transformers. Suppose we make a ground on the water and gas mains in an installation where one of the old type of transformers is in use. The result will probably be that discharges, either direct or induced on the line, will break down the insulation between the primary and secondary of the transformer and then take direct passage to the house. To my mind, all grounding should be outside of the buildings and the grounds should be well made. It is not always easy to secure a good ground and even where care is taken in the course of a year or two you have to go over the work and readjust the ground connections. If it is not made on the water pipes and gas pipes you have to go to considerable expense in making one that is satisfactory.

I therefore urge should the INSTITUTE *recommend that secondaries be grounded, that it also recommend that an insulation test be required wherever a ground is made.*

MR. GODDARD:—I take it the idea of Dr. Hutchinson is that the INSTITUTE should express itself as to whether it is advisable to permit the grounding of one wire. Then he goes on in his resolution authorizing the Committee on Code to confer with a similar committee from the underwriters as to details, and it will be noticed that the second resolution reads "the passage of a rule *permitting* or *requiring*," if it should be the result of that conference that the general opinion was that we should require the grounding, that might be the recommendation. It goes without saying that you want a good ground and a permanent ground. And that is the reason we want this conference to settle the details of any rule we may recommend. But they can't be settled here to-day.

MR. C. W. RICE:—The largest lighting interests endorse this resolution. In New York and Brooklyn the system is now operating with from 6000 to 7000 volts on the primary, and it would be a great advantage to all those interests if this change in the rules were made.

MR. HAMMER:—I think if the literature of the AMERICAN INSTITUTE OF ELECTRICAL ENGINEERS, the *National Electric Light Association*, the *National Conference on Standard Electrical Rules*, and the *Underwriters' National Electric Association* were gone through you would find this subject has been given a good deal of attention heretofore. It has been expressed by gentlemen here present that the principal difficulty was that the transforming apparatus had not arrived at that condition of perfection which would warrant such action being taken, and if it were held off the manufacturers might perfect the apparatus or find a satisfactory method of meeting the difficulty. At the time of the National Conference meeting I believe the best thing recommended was an automatic device which would open the primary circuit when the potential in the secondary rose above a certain value Prof. Puffer spoke of this subject being coldly received at the INSTITUTE meeting in New York City. There has not been an engineer who would give a decided expression of opinion on this point and back it up with the results of experiments which would warrant such an adoption. The question is an old one and I think the underwriters and certainly the National Conference at the time of their meetings thought the grounding of the secondary a thing which would eventually be done though it was hoped the manufacturers would submit something that would take the place of that. At any rate, the time had not then arrived.

PRESIDENT KENNELLY:—Before putting the question I may be permitted perhaps to make a few closing remarks. This is an old question. It has long been in existence and long been a matter giving rise to much difference of opinion, but especially between the underwriters and electrical people.

The facts are, as we know, that every low-tension system to-

day, of any kind, whether alternating or direct, when normally insulated, has its central point at the potential of the earth, and, therefore, so long as a low-pressure system is properly insulated it is normally subjected to the same conditions of pressure, the same breaking-down conditions, as would exist if a central point of that system were grounded directly, and only when a loss of insulation occurs on either side is that normal condition upset or modified. Moreover when a ground is made on either side, the conditions tending to produce accidents are worse than when the neutral or middle point of that system is permanently grounded.

As regards the argument that if the secondary circuits of transformers built in the past had been grounded at some point, they would have broken down, is that not a very weak position to take in regard to the security of life and property to-day, when if a high-pressure circuit becomes crossed with such a circuit we are likely to produce that very condition of breakdown. Is it better to lose a few transformers of weak insulation by grounding their secondaries, or to run the risk of accident from a high-pressure cross?

I do not know any man, conversant with the facts, who would let any person for whose life or safety he was responsible go into a damp cellar and touch any part of a secondary circuit when there was a high pressure turned on on the primary side. I want to see the man who would permit any child of his to do that thing unless adequate precautions were taken for protecting the secondary circuit.

The same is true in a modified form in regard to any low-tension system overhead or underground, Edison, direct or alternating. It is no argument whatever to say that owing to transformers being weak in the past this grounding of the neutral was objected to, because the way to make transformers better was to make manufacturers ground their secondaries. That would necessarily throw the full normal stress on the transformers and force the manufacturers to make the transformers capable of standing this full normal stress.

[After the presentation of certain amendments, the resolutions offered by Dr. Hutchinson were passed in the form in which they now appear on page 416 and the session of June 27th then adjourned.]

A paper presented at the 16th General Meeting of the American Institute of Electrical Engineers, Boston, June 28th, 1899, President Kennelly in the Chair.

PLEA FOR A WORKING STANDARD OF LIGHT.

BY S. EVERETT DOANE.

It was my desire to present what I am about to say as a part of the discussion on the report of the committee on the standard of light. As this committee will not report at this meeting, I bring the following before the INSTITUTE with no intention, of course, of interfering with the work our committee is doing. We all agree as to the importance of this work. What I wish to propose is that this committee or a new one, fix definitely the means for maintaining a working standard of light pending the adoption of a primary one.

There are scattered over the country many well equipped laboratories, and in the near future every central station and large isolated plant will be provided with means for measuring light. There is not now in existence any workable primary standard which can be used by the ordinary photometer corps.

It may be said that this is equally true of all primary standards. The mercury column or resistance standard, in fact presents so many difficulties that it is rarely ever used, even in our best equipped laboratories. In reply we can say that the standard of light differs from all these in that its terms are so indefinite and so crudely outlined that two laboratories cannot produce the same value for the candle power, if they work entirely independently. The discussion on this paper will probably bring out very diverse views as to what is the proper direction in which to work to eliminate our present difficulties with the light standard.

The standard of light is in quite another class from the other standards. Every instrument maker is anxious that his instruments shall be calibrated in true units and he can so calibrate

them if he uses care. He sends his instruments out so calibrated to the best of his knowledge.

A lamp user may say to the manufacturer, "Your standard is wrong," and neither ever dreams of suggesting a recalibration; they know by experience that an agreement cannot be reached. No observer can even duplicate his own work. What is the result? Every lamp maker in the country is sending out some lamps which are wrongly marked according to his own standards because some of his customers have standards of their own.

Lamp makers differ among themselves and there exists no way by which they can be brought together. It is obviously to the interest of the whole electrical engineering fraternity that some action looking to the correction of this condition be inaugurated.

In passing I wish to go on record as saying that in a very few years the incandescent lamp will be adopted as a primary standard. It could be so adopted to-day if lamp makers would only tell what they know.

Every committee (our committee included) ever having to do with investigation of proposed light standards has found an incandescent electric lamp a very convenient secondary standard. It has been entirely satisfactory, so much so that my whole purpose in writing this paper has been to see if we cannot inaugurate some action which will result in the appointment of a committee who will provide means whereby a standard of light may be arbitrarily maintained. This committee could send out under proper restrictions properly seasoned and calibrated incandescent lamps for this purpose.

It does not matter just how this is done. Possibly a national laboratory could be founded. A committee of the professors of electrical engineering from our various colleges might agree to do this for us. Something should be done, and the first step toward it will be the appointment of an INSTITUTE committee on the maintenance of what our committee on light may decide is a proper standard value. Such a decision will be arbitrary and may have to be changed later but what of that? We need now a common working standard of light.

That the discussion may be entirely free I refrain from making any definite suggestions until the views of the members may be obtained, but whatever these views may prove to be, I hope some action will be taken which will afford us temporary relief, and enable our committee on light standard to pursue its work un-

hindered by the necessity for hasty action. We can take action none too soon. A year from now, at the rate photometers are being made, we shall have as many standards of light as Joseph's coat had colors, unless something be done.

Discussion.

Mr. Steinmetz:—I think the matter brought here to our consideration is of considerable importance and for this reason I should hesitate to take any immediate and rash action.

I believe some years ago a committee was appointed to investigate photometric standards, and the committee made a preliminary report but has not yet concluded its work. I believe the committee was investigating the acetylene standard. Acetylene appears to me to offer unusual advantages as a standard of light since it can easily be produced in chemical purity from copper acetylide Cu_2C_2, and its light has a perfectly white color equally suitable for incandescent and arc light photometry. The amyl-acetate standard while by far the best available at present, has a number of serious disadvantages, being somewhat inconvenient to handle, and especially differing in color by its reddish light considerably from the color aimed at in artificial illumination.

Regarding absolute measurements of light, I see no reason why this should not be possible. It is true that light is not a physical quantity in the usual sense, since as light is understood the radiating energy in that range of wave lengths where the radiations are visible to the human eye. A photographic plate for instance, "sees" another and a bolometer still a different range of ether waves. Still, however, it should be possible to define as the total light intensity the energy of the ether waves within the wave lengths from 3,900 to 7,000 which is about the visible range.

Mr. Charles P. Matthews:—I might say a word about the committee which Mr. Steinmetz refers to. Some four or five years ago a committee was appointed of which Dr. Nichols was chairman and of which I had the honor to be a member. We made a report of some forty or fifty pages, the object of which was to show how poor the standards were. We succeeded in accomplishing that. Since that time we have not done anything collectively as a committee, although we have done something individually. Dr. Nichols is at work on some standards. I hope to see recommended in the near future a standard that will be of some service. I am confident that it is not a problem that is beyond solution. At present the best standard in my opinion is the amyl-acetate standard, in opposition to Mr. Steinmetz's opinion, because it is the steadiest standard. It is the most independent of the quality of the material burned—that is you can burn it with a considerable degree of impurity and still get the same intensity of light, and it is reproducible in a high degree. The qualities wanted

are steadiness and reproducibility. That is, you want in Boston and New York and San Francisco a standard which will come up to the specifications without having a necessity for a central bureau. First, steadiness and second reproducibility, third, quality. That brings in a point of importance. It is clear that the arc light differs so greatly in quality from the incandescent lamp that we cannot employ the same standard for the two. If we wish to measure the arc lamp to-day it is necessary to proceed stepwise. By so doing you can eventually reach a standard which has approximately the same color as the arc and you reduce the error to a minimum. I think there is no reason why we should attempt to measure arc lights by the same standard as glow lamps. I am quite in sympathy with Blondel of Paris who has suggested an arc light standard, a standard obtained by screening off a portion of the crater of the arc. That to be used solely for arc light. Unfortunately it has been shown that the intensity of such a standard is not entirely independent of the quality of the carbons used, but I am in sympathy with the principle there that we should have a standard for arc light photometry. I think in conclusion we may well adopt a provisional standard. I know of no better standard than the amyl-acetate. We may indicate the character of the fluctuations which are due to the amyl-acetate standard in comparison with the others. If you take the amyl-acetate standard and set it up before a bolometer in the manner done by your committee you get a record which shows the steadiness of that standard. The records of Mr. Sharp and Mr. Turnbull which were put in that report I refer to, are something like this in a very crude way. That shows the reproducibility of the standard at any rate. You are able to get the same thing at different times. Of all the standards tested by the committee, those fluctuations were the smallest, the steadiness was the best. Therefore as a temporary standard I don't think we can do better than to accept the amyl-acetate standard.

The President:—It may assist the deliberations to state the facts in a small compass. The Institute appointed some time ago a committee to report upon the question of a luminous standard and the means for obtaining measurements from the same. That committee has reported that the amyl-acetate lamp is the best standard available to day, and that in using this, certain precautions should be taken in comparing incandescent lamps. Mr. Doane's suggestion is that the primary standard is of very little practical importance, and that what is wanted is a stock of secondary standard incandescent lamps which have been standardized by some recognized authority.

Prof. Goldsborough:—I think at the present time we are in a position to look to the organization in this country of a standard laboratory and to my mind the Institute could not engage in a more profitable undertaking than that of looking into this mat-

ter, and seeing if it is not possible either for the INSTITUTE alone or for the INSTITUTE in connection with other societies in America, such as the *National Electric Light Association* and the Fire Underwriters, or for the Government, to establish such a laboratory, that we may have a recognized laboratory, where we can send both lamps and instruments and other things and feel that they will receive proper attention in the hands of unbiased parties. I believe it is something we need in this country as much as any one thing, and personally I am greatly interested in it and I feel it is one of the things the INSTITUTE must take up in time, and the sooner the better.

MR. BLOOD:—This has been one of my dreams as well. The trouble comes in the case of either the real or assumed engineering quality of the different societies. There are certain of the engineering societies that have associated under the name of the Association of Engineering Societies, but the four large societies, mechanical, electric, civil and mining engineers, have hitherto kept apart. It would seem to me that in a general association of these large societies there might be a general arrangement whereby certain projects which would be impossible in a single society might be taken up in connection with others, that would be a good thing.

MR. A. L. CLOUGH:—This matter has I think been taken up by other than technical societies. If I remember rightly the American Association for the Advancement of Science at the last meeting dwelt somewhat on this matter and it would seem to me that the scientific societies could throw their whole influence together to that end.

MR. STEINMETZ:—From this discussion it seems to me that we are not quite ready to take up this matter. Undoubtedly if the Government could be induced to interest itself therein, the standard given by the Government might be expected to be accepted as authority, and universally followed.

PROF. W. M. STINE:—A suggestion is made in the paper regarding the adoption of the incandescent lamp as a primary standard of light. In 1885 a committee of the British Association[1] brought forward in a formal resolution that "a unit of light is obtained from a straight carbon filament at right angles to the middle of the filament, when the resistance of the filament is one-half of its resistance at 0° Cent. and when it consumes 10^9 C.G.S. units of electrical energy." It was further proposed[2] to make a large number of subjective experiments on human eyes to obtain a coefficient for the expression of the illumination from the standard lamps by the change in the resistance of the filament.

In such manner when comparing sources of illumination, the standard filament might be adjusted until the spectrum curve of

1. *Brit. Asso. Rep.*, 1885, page 63.

2. Ref. Cit. page 83.

its radiation should be that of the light compared. Then the total heat and light radiations of the illuminating source and the standard lamp could be compared at equal distances by means of a thermopile. From the known radiant properties of the standard lamp, established by researches on the standard filament, the compound light could be completely defined.

Abney[1] had already proposed the definition of a standard of white light by experimentally establishing formulas which should connect the radiation from the filament with the energy current electromotive force, resistance and temperature quantities. He proposed the adoption of a standard spectrum for the comparison of the quality of lights, the quantity to be determined photometrically.

The dimensions of the carbon filament and the electrical quantities involved in its operation are all capable of ready and exact determination. It would thus seem admirably adapted for a standard light or an absolute photometry standard, in the sense that its light radiation might be completely specified by reference to the dimensions of its filament and its temperature of operation: or that the quantity of light Q should be

$$Q=f\,(A.\ S.\ T.)$$

when the functional dimensions refer in their order, to the emissivity, the acting surface and the temperature.

Further, such a standard as was pointed out in the British Association report, would be exceedingly flexible, and not only capable of adjustment to agree in quality with the compared lights, but from the continuous nature of the spectrum of carbon at a certain temperature it would conform to the requirements for normal quality of light. Certainly no source of illumination as yet proposed for a standard light has so many obvious advantages.

The failure of the incandescent light to fulfil its promise of becoming an exact standard of light has been due to a lack of reproducibility and constancy of its physical character when in operation. Though it would seem to be difficult to determine with accuracy the area of the hot radiating surface, yet doubtless this could be accomplished were it the only obstacle.

The essential difficulty results largely from the tendency of carbon to assume an allotropic form at very high temperature. It is seemingly impossible to produce homogeneous carbon filaments or to flash filaments until the surface assumes known radiating qualities.

The presence of graphitic carbon greatly modifies the temperature change of resistance so that the specification of a certain change of resistance to define the temperature is not feasible. The proposition that the operating temperature shall be defined by a decrease of the resistance to one-half of its value at 0° C. loses all certainty through the lack of homogeneity in the

1. *Brit. Asso. Rep.* 1883 page 422.

filament. A further difficulty is introduced by the rapid change of resistance due to hysteresis and its low progressive rise due to molecular readjustment or annealing.

The variation in the emissivity, both in the same filament and between different filaments is an added uncertanity. Join to these the influence of the blackening of the chamber walls, their indefinite absorption, and the vaporization of the filament, and the causes for the failure of the promising standard are apparent. The failure, briefly, lies in an inability to establish the light emitted as a function of the dimensions and physical properties of the filament.

Even should the manufacturers by refinement of their processes attain a fair certainity and uniformity of the product, these objections would still remain in force against the lamps beco.ning exact scientific standards of light.

I would especially call attention to the frequent statements berating the accuracy of photometric measurements. It will not do to speak of photometry as an inexact science and to claim that different laboratories cannot get concordant results. In 1895 Liebenthal[1] showed why such results were not concordant. He showed us the value of the temperature correction and most of all, the humidity correction. Introducing these corrections, when the color of the lights compared does not materially differ, the amyl-acetate or pentane standards will lead to very excellent results. Lack of precision can now justly be laid to the failure of the photometrist and not to the method of photometry.

Mr. Doane :—I made a series of investigations once, extending over several weeks, and during that time I found that carbon surfaces of the two kinds gave only two emissivities; that is all "treated" carbons which I tested gave exactly the same illumination per unit surface per watt radiated. There was absolutely no difference over wide ranges of specific resistances and specific gravities of these carbon deposits. You can make deposits from any hydrocarbon or alcohol or any carbonaceous fluid and (so far as I have investigated) the light radiated per unit surface per watt will be absolutely the same.

The manufacturing companies to-day know a great deal about making incandescent lamps to an exact candle power. They find it difficult to make lamps to an exactly predetermined constant because they can't make their resistances and their surfaces what they wish. When it comes to predicting what candle power a carbon will give at a given voltage after the lamp is made, that they can do within close limits. In the course of two or three years there will undoubtedly be presented to the world satisfactory instructions for making some kind of a primary standard. What we need now is a way of getting together practically rather than theoretically, and I hope that this discussion won't end until

1. *Elektro Tech. Zeit.*, Oct. 1895.

a plan is suggested. I hope you will suggest some scheme by which we can maintain the standard of light. The amyl-acetate standard is not interpreted by various institutions or laboratories in the same way, that is they do not give the same values, consequently we are practically without a standard to-day.

PROF. PUFFER:—I have been very much interested in listening to the discussion and (as the result of a great many experiments) I want to suggest a correction which ought to be applied to nearly all photometers, and that is a percentage correction for the common sense of the observer. What I mean by that is shown very forcibly by a set of observations I call to mind which were taken by a so-called skilled observer who carefully set up a photometer in a whitewashed vault. The lamps he tested were unusually near the whitewashed wall and the efficiency was remarkably high. Of course that was a very rank case but you will find that the reason for a great many small discrepancies in such standards as we have, is due almost entirely to utter neglect of common precautions of screening the reflected light from the lamps under comparison in the photometer itself. Probably everybody in comparing standard lights against one another would put the lamps at the opposite ends of the photometer. If they would oftener try the experiment of reversing the photometer, disk and lamps they will find much better and concordant results. I agree with a number of gentlemen who have said that the amyl-acetate standard is not a favorable one on account of its color, but I believe the amyl-acetate flame when used in lamps provided with a screen having a hole of a certain size will be found satisfactory. The bulk of our experience here points very decidedly in favor of a screened flame. I agree with Mr. Doane that it would be very desirable for the INSTITUTE to go on record as saying that for the present it seems desirable to take the amyl-acetate lamp as a standard and taking a certain value of it, and using that as a standard of light for the time being and the added precaution that both be placed at the same end of the photometer.

[COMMUNICATED BY REGINALD A. FESSENDEN.]

In previous communications[1] by the writer the following were suggested:

1. A standard of radiation.

2. A standard of light (to be used as primary standard), which need not be accurate to much within one-half per cent., in view of the great difference between the eyes of different observers in regard to visibility of light of different wave-lengths.

3. A secondary standard of light, consisting of electric incandescent lamps of 16 C. P., the filaments being placed in bulbs of exceptionally good vacua and of the size used for 100 C. P.

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1. TRANSACTIONS A. I. E. E., vol. xi., p. 110; vol. xii., p. 500; vol. xiii., p. 201

Since the publication of the above the following points have been noted: That as the yellowish green part of the spectrum seems to be the most constant in physiological effect, the standard of luminous effect should be one watt of light of this wave-length.

That the blackened copper ball suggested by the writer as a standard of radiation does not give a perfectly uniform distribution of radiation; or rather, that the presence of convection currents in the air interferes with the uniform distribution of the radiation, as one part of the ball is thus rendered slightly hotter than another. This might be obviated by placing in vacua, but other difficulties are thus introduced. The solution finally adopted is that of having a plane surface of copper of large extent, blackened with platinum black to a fixed degree determined by the current passed. This method of coating with platinum black was first suggested by Lummer and Kurlbaum, and with wires placed within the copper slab of such resistance and carrying such current that .01 watt is radiated per square cm. of surface of the slab; the slab to be one metre in diameter, of circular section, one cm. in thickness and its back and sides covered with a layer of three cms. of eider down; the slab to be supported in a horizontal plane, and face downwards, and with a rim around it. Under these conditions it has been ascertained from preliminary experiments on a disk of smaller size, convection currents play a small part and the radiation to a point placed 10 cms. from the face of the plate is very closely the theoretical amount.

In use with this standard, the balance thermopile described by the writer in a previous communication must have its faces at right angles, like the letter L, and be reversible, as before.

As regards the acetylene standard, in view of the fact that the University has not seen fit to make any appropriations for scientific work during the last five years, and the writer's personal means have been taken up in working along a different line, but little further has been accomplished. The two-jet burner described by the writer has been generally adopted in commercial acetylene lighting, with however one modification which should be avoided, *i. e*, the introduction of holes in the tips for leading in air. If the pressure is high, as recommended originally, and the tips are of platinum, or platinum iridium, preferably blackened, the tips never get hot enough to decompose the acetylene and form benzene and no smoke is produced. If it were found desirable to lose less pressure the tips might be artificially cooled, but the writer believes the high pressure best.

PROF. GOLDSBOROUGH:—In order that we may bring this discussion to a focus I move you that a committee of the INSTITUTE be appointed to look into the matter of supplying standard lamps to those desiring them, these lamps being compared and standardized by the committee in such manner as it deems best and most accurate. I don't mean that the INSTITUTE shall order

the committee to proceed with this work directly, but that the committee be directed to take steps toward it, and by consulting with the Council determine finally what is the best plan; and that this committee be also recognized by the INSTITUTE as having in its charge and in its care the matter of the development of a laboratory for standardizing lamps and instruments. My recommendation is for the appointment of a committee which shall make its report to the Council rather than the INSTITUTE. It seems to me we can safely place the matter in the hands of a committee acting with the advice and consent of the Council.

THE PRESIDENT:—The one point to be remembered is that this is a matter of ways and means and an expenditure of time and money, and that should come from the Council unless the INSTITUTE is prepared to vote an appropriation.

PROF. GOLDSBOROUGH:—Then I should be in favor of empowering the Council to spend such funds on this matter as in its judgment is a reasonable expenditure in this connection at this time.

THE PRESIDENT:—Will you kindly crystallize your motion then and present it to the meeting?

PROF. GOLDSBOROUGH:—I move that a committee be appointed to have in its care the furtherance of the establishment of a standard laboratory for testing lamps, instruments and materials, and that this committee look into the matter of standardizing incandescent lamps for the general profession, such lamps to be compared and standardized by methods which the committee shall devise. That further this committee shall make its report to the Council of the INSTITUE with which it shall advise, and the Council is authorized to promote the work of this committee financially as shall in its judgment seem best.

MR. MATTHEWS:—I second that motion, with the idea that the committee will take a little broader view of the laboratory than expressed in those words.

MR. C. W. RICE:—I would like to ask if that is in a form that you yourself say can be carried out.

THE PRESIDENT:—As I understand it, this matter will be left to the Council and this is a recommendation to the Council of the sense of the meeting; consequently it remains with the Council to say whether they can see their way to carry out the wish of the INSTITUTE.

PROF. GOLDSBOROUGH:—And that the INSTITUTE gives the Council the power to act as far as an appropriation of funds for the work is demanded.

MR. STEINMETZ:—I should however like to amend this recommendation to that extent that this committee is empowered or requested to confer with the large lamp manufacturers so as to gain and secure their experience in this line.

MR. RICE:—I should like to amend by including the *National Electric Light Association.*

Mr Doane:—And others prominently connected with the work.

[Motion adopted.]

Mr. Hammer:—I should like to call attention to the fact that Mayor Quincy who honored us with his presence the other day; delivered an address in Philadelphia during the recent Franklin celebration, during which he stated that Benjamin Franklin at the time of his death had left a sum of money to the City of Boston, which has since increased I believe to four hundred thousand dollars; and at the present time the authorities are considering seriously what is the best thing to appropriate this money for; it has occurred to me that possibly in view of the manner in which the Mayor expressed himself the other day it would be well for this committee to communicate with him, with a view that possibly this sum or at least a portion of it which has been so long kept intact and which I understand the authorities are now ready to appropriate to some purpose, might be appropriated in this direction and it seems to me it would be a most excellent way of perpetuating Franklin's name and fame.

Mr. Blood:—The object of Franklin was to promote industrial or trade schools for the city of Boston, although it is not definitely stated. He gave it to certain clergymen and the Selectmen of the City of Boston as trustees and there is great trouble here now to determine who should act as trustees. The Aldermen claim they are descendants of the selectmen, and the Council claim *they* are, and the Aldermen and Councilmen so far outnumber the three prominent divines that the divines do not have the representation that was intended.

The President:—If there is no further discussion upon this paper we will now pass to the next matter.

Mr. Hammer:—I move that the Chair appoint a committee to prepare a set of resolutions expressive of the appreciation of the Institute of the many courtesies that have been extended to them.

The President:—It gives me great pleasure to put that motion, seeing that we have received many courtesies through the exertions of the Local Committee.

[Motion adopted.]

The President:—The Chair will appoint a committee of three to draft suitable resolutions to be presented before the close of this meeting, that committee to consist of Mr. W. J. Hammer, Mr. H. Ward Leonard and Mr. W. D. Weaver.

Mr. Alton D. Adams then presented the following paper on "Motor Speed Regulation."

A paper presented at the Sixteenth General Meeting of the American Institute of Electrical Engineers, Boston, June 28th, 1899, President Kennelly in the Chair.

MOTOR SPEED REGULATION.

ALTON D. ADAMS.

While great advances have been made in the application of alternating machinery, the distribution of power by direct currents was probably never increasing faster than to-day.

Tens of thousands of horse power are now delivered by direct current motors, and a large part of this work is done at variable speed.

In spite of this extended use, the direct current motor as commonly used for variable speed is by far the least efficient link between the central station engine and the consumer's machinery.

This lack of efficiency is by no means inherent in the motor but results from the common method of speed regulation by the use of a variable resistance in the armature circuit.

As the case now stands, the central station furnishes about 80 per cent. of the power developed by its engines to consumers. Manufacturers provide motors of from 80 to 90 per cent. efficiency at full speed and load, and the user in order to regulate the speed to his requirements commonly employs a method of regulation which reduces the efficiency of his motor to 50, 25 or even 10 per cent.

Consider for example a motor having an efficiency of 86 per cent. at full load and speed, with losses of 3 per cent. in armature windings, 3 per cent. in shunt magnet winding and 8 per cent. local currents, friction and hysteresis.

Let this motor be loaded to full and constant armature current and then regulated for variable speed by a resistance in the armature circuit.

As the energy entering the armature circuit is 97 per cent. of that drawn from the line, and the loss in armature winding is 3 per cent. of the total, this winding loss is .03 ÷ .97 = 3.09 per cent. of the energy entering the armature circuit.

The pressure required to force the full current through the armature resistance is therefore 3.09 per cent. of the line pressure.

The counter electromotive force of the armature at full speed will be 100—3.09 = 96.91 per cent. of the line pressure, and at one-fourth speed the counter electromotive force will be 96.94 ÷ 4 = 24.22 per cent. of the line pressure.

At quarter speed, then, the rheostat in armature circuit must consume 100—(3.09 + 24.22) = 72.69 of the line pressure, and as 97 per cent. of the total energy is delivered to this circuit the rheostat in this case consumes 97 × .7269 = 70.5 per cent. of the energy taken from the line.

Assuming that the losses from local currents, hysteresis and friction vary directly with the speed, the losses internal to the motor at one-quarter speed, become (8 ÷ 4) + 3 + 3 = 8 per cent., and the total losses in motor and regulator became 70.5 + 8 = 78.5 per. cent., thus giving the combination an efficiency of 100 — 78.5 = 21.5 per cent. at one-quarter speed.

At less than constant torque and armature current, the combined efficiency will evidently be lower than above figures.

As there are well known methods of speed regulation which involve only the small losses internal to motors, whatever the speed, it seems that a stronger effort on the part of manufacturers to introduce machines with efficient means of speed regulation, would benefit all concerned.

Two practical methods of motor speed regulation are the variation of magnet strength, and the variation in arrangement of armature conductors as to each other.

A rheostat in the shunt magnet winding, gives any desired speed above the minimum, with constant armature capacity, and two or more separate windings and commutators on the armature, give two, three or four times the minimum speed, with corresponding increase in armature current capacity.

The work required of variable speed motors is of three kinds, namely, constant whatever the speed, varying directly as the speed, and varying directly as same power of the speed.

These three classes of work are illustrated by machine tools,

which require, when in use, nearly constant power for all speeds, by shafting which consumes power nearly as its speed, and by centrifugal fans whose driving power varies as the cube of their speeds, friction aside.

As constant power at all speeds involves a constant armature current, it is well provided for by a variable magnet strength to correspond with all desired speeds, but special proportions are necessary to avoid sparking with a constant armature reaction and weak magnets at the higher speeds.

When the required power and consequently armature current varies directly with the speed, the armature reaction, winding loss and magnet strength may be held constant, and the desired speeds secured through two or more separate windings and commutators, provided a reduction of the maximum speed to one-half or one-quarter is sufficient.

If the power and armature current must vary as the cube or other high power of the speed, it is well to combine the method of multiple armature windings with the variation of magnet strength, as the variation of armature conductors which gives the desired speed does not in this case afford proper current capacity.

It is certain that motors constructed far above methods of speed regulation will cost more than those of ordinary type, whose speed can only be regulated by a resistance in the armature circuit.

It is equally certain that the saving of energy effected by the more efficient means of speed regulation will soon offset its increased cost in any given case.

Efficient means of regulation in variable speed motors will benefit manufacturers through the sale of more valuable machines, the consumer by a reduction in power bills and central stations and manufacturers alike in the increased use that a large reduction in the cost of operation will produce.

Attention is called to these facts, not because they are new, but because their importance entitles them to more consideration than they have received.

Discussion.

Mr. John B. Blood :—In this connection I think most every engineer appreciates this paper, and in view of the fact that there are so many methods in the market it is bound not to go without appreciation. It is generally found I think that the extra complication for small apparatus will not pay for the economy gained, on account of the fact that the total watt hours of small apparatus do not figure to any large extent. In this connection I will mention that there is one method that has not been brought out, namely the method of variable electromotive forces.

There are four methods used to do this work; the methods of auxiliary machines like those of Leonard and Burke, and there is one other which has no name; the method of varying the polarity of which there are a great many, Professor Anthony has one, and Bauck in Germany and Rechniewsky in France and a number of others. Then the method of two commutators, which has not been used much in this country, that gives two speeds, and in Germany they have combined that with the variable field to get seven speeds, three in parallel position and four in series position. This method is used in connection with water pumping to quite an extent, and there usually the two speeds are sufficient without the variable field. Then the last method as I mentioned above is the method of variable electromotive forces. This has been used to some extent in this country and by Mather and Platt in their printing presses for cloth. They use three different voltages, combine them in different ways, which gives them with variation in the field strength as they claim, fourteen different speeds. In this printing machinery the actual speed is of more importance than the efficiency; and efficiency would not be considered if speed could not be obtained. Mather and Platt I understand obtained good results with their apparatus. There are some printing machinery plants used in this country with the variable voltage method. It is used in Cocheco. The Leonard system is used at Pawtucket. The auxiliary machine system where the voltage is varied from zero to the maximum gives the most desirable range for cloth printing machinery.

There is one point in connection with this variable speed, that is the torque of the motor is proportionate to the weight, and as with a given motor you cannot change design so as to get more than a certain torque, therefore the power at the maximum speed is the maximum power. So that in a combination where power is constant, independent of speed, you always have as a maximum power that obtained at the maximum speed. This is a point which is encountered in connection with machine tools, where the speed in cutting is constant, the power is constant and the torque will be proportionate to how far the tool was from the center.

Prof. C. A. Adams :—The shunt motor with variable field

gives constant power at all speeds and is therefore the natural type for the driving of machine tools, the only objection being the narrow range of speeds that can be obtained without destroying the commutation. We have in our laboratory a 30″ motor-driven lathe, in which the above method is employed, a wide range of speeds being obtained by means of Ryan balancing coils. This motor operates sparklessly at all speeds and at all loads. It was designed by students.

[In the absence of the authors, the following paper on "Electricity in Coal Mining" was read by Prof. D. C. Jackson.].

A paper presented at the 16th General Meeting of the American Institute of Electrical Engineers, Boston, June 28th, 1899, President Kennelly in the Chair.

ELECTRICITY IN COAL MINING.

BY JOHN PRICE JACKSON AND FRANK F. THOMPSON.

The statements in this short paper on the use of electricity in mines refer especially to the mining of soft coal. Of the essential elements in operating such mines, two of the most important are: first, apparatus to obtain efficiently the rapid handling of the coal; and second, to do this with the least possible number of openings. These conditions have evidently been large factors in causing the application of electricity to such operations.

The applications of power to mines, which we wish to consider, are principally for, (*a*) lighting, (*b*) haulage, (*c*) cutting or drilling, (*d*) pumping and driving fans.

Systems.—The systems worth considering which are in use at present may be tabulated as follows:—

1.—Rope haulage, and steam for all other purposes.

2.—Electric haulage and compressed air for other purposes.

3.—Electric haulage and electricity for other purposes.

Various other combinations are, of course, used, but these three will serve the purpose, as representing well-defined types.

Rope Haulage and Steam Power.—In the past, this system has been the standard, and even yet in many portions of the hard coal fields has a very firm hold. Experience has shown rope haulage much inferior to electricity in point of working economy, as is now being illustrated by the continual substitution of electric for rope haulage now going on in the soft coal field.

The Mitchell Coal and Coke Company had two mines running for some time at Gallitzen, Pa., under exactly similar circumstances, but one using rope, the other electric haulage. It was quickly proven that the electric was far preferable.

Steam power for pumps and fans in the mines has likewise been shown by experience to have many faults. Timbers along which the pipes pass rapidly deteriorate. The piping is expensive to install and can only be kept in good condition by constant attention. If the lines are long they are a source of large loss of power by radiation and condensation, even when well covered. They are a nuisance in the mines because of their high temperature. The steam motors are expensive from the standpoint of repairs and attention. Steam cutting and drilling will in most cases prove unwieldly. Mines operated under this system are without suitable means of lighting, an important matter in rapid operations.

Electric Haulage and Compressed Air Power.—The Berwind-White Company's mines at Windber, Pa., furnish an excellent example of this system, and so far as known it has given complete satisfaction. This plant, which has now six mines in operation with an output capacity of 5,000 tons per day, is eventually to be increased to ten mines with 10,000 tons capacity. The haulage in the mines is done by electricity, while the drills, interior pumps, and fans are driven by compressed air. The use of compressed air has many obvious advantages. It is found that the machinery, working under the extremely severe conditions to be found in a mine, performs its duty well. It requires little attention and is thoroughly reliable. On the other hand, pipe lines in extended mines are expensive to lay and keep in repair. The pipes soon deteriorate and when the lines are removed from old workings it is usually found that much if not all the pipe is in too bad shape for further use.

The flexibility of the system, or its adaptability to quick changes, is not satisfactory.

Electric Haulage and Power.—For convenience in discussion this head may be divided into two sub-systems as follows:

(*a*) Direct currents for haulage and other power.

(*b*) Direct currents for haulage, and polyphase currents for other power.

The use of direct-current machinery for pumping and fans has not been found satisfactory in many instances. One large company after a thorough trial of such apparatus rejected it in favor of compressed air. The pumps in a mine are subject to only rare inspection and that, oftentimes, by unskilled work-

men. These conditions combined with the unfavorable location of the machinery will soon cause electrical troubles in the commutator, or elsewhere, of the most carefully constructed motor. Inasmuch as the stopping of a pump, even for a short time, may cause excessive damage, the use of such a motor is a constant menace.

The second electric system, that using direct and polyphase currents has the inherent disadvantage of requiring the installation of two distinct and separate sets of generators and wiring. That is a matter of serious importance as will be indicated later, but is neither so expensive nor cumbersome as the piping used for compressed air. The great advantage in the use of polyphase currents, lies in the fact that they permit the use of a motor that is perfectly reliable under essentially all conditions of operation to be met with in mining. This compound electric system seems without doubt to be the best that can be installed for large operations. It comprises the advantages of all the other systems while eliminating their most serious defects. A system using polyphase currents alone might possibly prove more advantageous, but would have the serious defect of requiring two trolley wires, and even if this difficulty were overcome it would have to await the development of a polyphase motor suitable for a mining locomotive.

The Davis Coal and Coke Company.—The Davis Coal and Coke Company's plant at Thomas, West Virginia, is so efficiently equipped with this compound electric service as to be worthy of a short description. The company operates two mines at Thomas, the Thomas drift and the Davis shaft, and one mine at Coketon, a drift.

The power station is a roomy brick building containing an Ames 200 H. P. engine direct connected to a 150 K. W. 500-volt direct-current generator; two Atlas cycloidal heavy duty engines of 150 H. P. one of which is belted to a 100 K. W. 550-volt three-phase alternator, and the other to a 76 K. W. 550-volt direct-current generator. The last mentioned generator has been installed temporarily in the place of a second 100 K. W. three-phase 550-volt alternator which had been operated in parallel with the other three-phase alternator. This 75 K. W. machine is used to help the haulage generator.

The coal is hauled by horses from the "rooms" to convenient points where it is collected into "trips" of from six to

twelve "wagons." The inside haulage motor, a 14-ton G. E. T. M. M. 35, takes these "trips" and hauls them to a central point of the breast and there they are combined into larger "trips" of about 15 to 35 wagons and hauled to the mouth of the mine by another similar motor. Each of the haulage motors gives 3,500 lbs. draw-bar pull. At Coketon, two miles away, another 14-ton haulage motor is installed.

The alternating three-phase generator is used for operating three 10 H. P. induction motors for driving small pumps, one 5-H. P., one 10-H. P., two 20-H. P., and one 30-H. P. induction motors for operating elevators; one 5-H. P. induction motor for a car lift; and three G. E. chain coal cutters. The induction motors for driving the pumps are located at the foot of the side entrance both at Thomas and Coketon. One 10 H. P. induction motor connected to a pump having a 5-inch suction 250 ft. long, and a 4-inch discharge pipe 750 feet long, with a total elevation of 28 feet, pumping 106 gallons per minute, was tested and found to take 11,000 watts. Induction motors are also used for driving fans, and conveyors which carry the slack coal from beneath the screens to the bins where it is stored until needed to charge the coke ovens.

Haulage.—Electric haulage equipments have been so long in use as to be now in a thoroughly good state of development. Even yet, however, the following faults may be observed in some of the machinery: Poorly acting brakes, unwieldy arrangement of the various controlling levers and trolley poles, brake rods or other projections too close to the track, and unsatisfactory speed and power regulation. Although some of these seem of small importance, any one of them is apt to seriously interfere with efficient work. The brakes on a mining locomotive should be very powerful and quick acting; likewise the arrangement of motorman's seat, brake handle, controller and sand-box lever should be such that the motorman can control his machine with the greatest possible dispatch and ease. Locomotives have been placed in mines with absolutely no provision for the motorman, and others where the lever arrangements are so unwieldy as to make the quick control necessary to safe operation impossible. In large coal operations economy is often to a large extent dependent upon the rapidity with which the wagon trains can be moved. Heavy grades both in favor of and against the load are frequently to be found. In order to draw a large

load and make quick time, the design and control of the motor should be such as to give an unusually great draw-bar pull at low speed, and at the same time have points of comparatively high speed. This condition is not properly met at present by all of the mining locomotives in operation. In one mine, which has come recently under the writer's observation, a slightly different design and arrangement of control in the locomotive would permit the handling of much larger loads at a great saving.

The power-house load curves for haulage are naturally very similar to those of other electric railway work. Fig. 1 shows curves for three stations. Curve No. 1 was taken at the Davis Coal and Coke Company's mine at Thomas, W. Va., two 14-ton

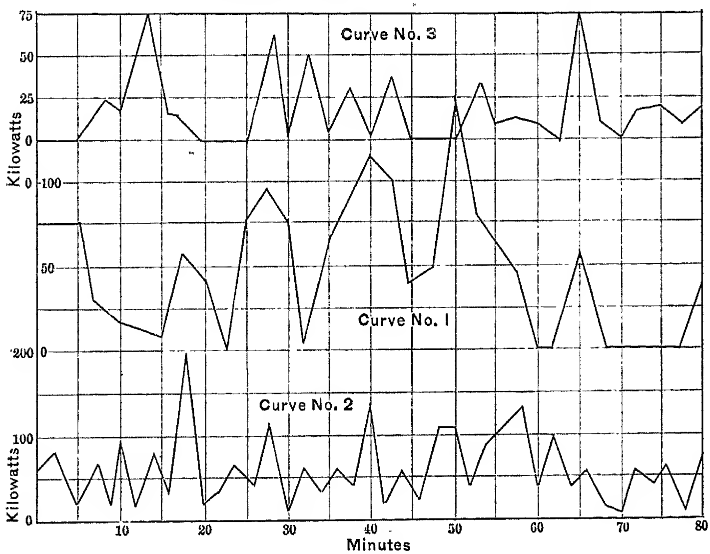


FIG. 1.

locomotives of 70 H. P. were in service hauling the regular output which in this case amounted to about 1300 tons per day. Curve No. 2 was taken at the Berwind-White Company's mines at Windber, Pa. Five locomotives of 12 and 20 tons are installed in this mine. Curve No. 3 was taken at the Davis Coal Company's mine at Coketon, Va. One motor of 14 tons was operating at the time.

Coal Cutting.—Under suitable conditions under-cut coal cutters will permit a great saving of labor, and therefore of expense, in soft coal mining. But in a large number of cases such cutters have been thrown out as unsatisfactory and have been replaced

by compressed air drills or other apparatus. In mines where curve veins abound they have ordinarily given much trouble. The cutter strikes the clay vein and sticks, or worse, bends, causing it to wedge tightly. This necessitates digging out with the pick-axe and expensive repairs. The most serious difficulty seems to arise from poor mechanical design and construction, combined sometimes with electrical faults. It should be possible to overcome these difficulties. In one mine where great trouble of this nature was previously experienced a new set of machines is now giving great satisfaction.

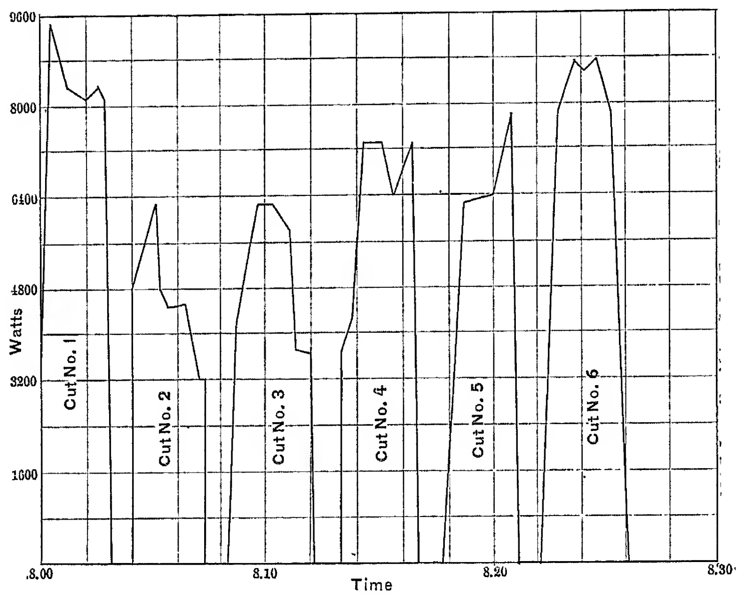


FIG. 2.

Figure 2 gives the power curve of a 20-H. P. cutter working in the mines at Gallitzen, Pa. In cases when under-cutters cannot be made to work, there seems no valid reason why electric drills could not be substituted, which would give as good service as compressed air, while at the same time preserving the valuable advantage of an all electrical plant.

Electric Pumps.—Electric pumps run by induction motors give very satisfactory service. The conditions met with in mining often necessitate frequent re-location of the pumps and in this respect the electric pump is by far the most satisfactory.

The attention required is certainly a minimum. A particular pump tested ran about ten hours per day, and the only attention required was that necessary for starting, stopping, and lubrication. Some mine owners have objected seriously to the electric pumps. In most cases these objections have been due to the compact arrangement of the pump and motor. In one mine which came under our observation, a 10-H. P. pump, which was bought with the motor, was replaced by the water end of a steam pump with a great improvement in the service. If electric motors were made to suit the pumps, and not the pumps to suit the motors, it would go far toward obviating the most serious objections. When the pump must be of large capacity and when it can be located within a reasonable distance of the steam plant, a steam pump would probably show greater economy.

Wiring and Pressure.—Wiring in mines is subject to certain restrictions which do not apply in ordinary wiring. There is no doubt that the 550-volts used for haulage is dangerous for horses. It is therefore customary in many mines to shut off the trolley current while the mules are being taken in or out of the mines. If a polyphase system is installed for operating cutters, pumps, etc., in the mine it should be run through the air courses and not through the main gangway. A pressure of 550-volts alternating is much more dangerous than the same direct-current pressure. The class of labor which is usually employed in the soft coal fields is of a low grade of intelligence, and many instances are recorded of serious personal injury or loss of life from accidental or intentional contact with the wires on both 500-volt A. C. and D. C. service. Although the mine laborers may have been repeatedly warned of the danger, they continue careless about the wires. When the mine roof is low enough to be reached by the men, the common practice is to run the trolley wire along one side supported by the usual hangers. When feeders are necessary they should be run along the same side. The other side of the roof should be kept clear.

Ordinary bare wire is preferable in mine work. The best insulation, rubber compounds, deteriorate rapidly under the action of the sulphur water. Any other insulation soon becomes inefficient owing to the moisture which is always present in a mine.

In large operations such as those at Windber, where 20 miles

of trolley are already in service, it is undoubtedly advisable to use at least 500 volts pressure for haulage. The polyphase power should preferably be used at a lower pressure for the sake of safety to employees. This could often be done without an undue expenditure of copper, by carrying high-pressure lines overhead to air ducts, or through unused passages to suitable points for distribution, where the pressure could be lowered by transformers. When it is necessary to run wires down a shaft through which coal is to be hoisted, the best practice would be either to use lead covered cable, or wire which has been insulated with rubber, heavily braided, and drawn into an iron conduit having the ends hermetically sealed. In many instances when wires have been installed without such protection, in old shafts, trouble has resulted from the breaking of the wires, caused by lumps of coal falling down the shaft, etc.

Skilled Employees:—Too much pains cannot be taken to employ careful men as motormen for the haulage motors. The mine track is far from being up to the street railway standard. To haul a long trip of wagons over a bad track, requires careful handling of the motor. The motorman should be trained to study his track and his load, and know when and where to let his trip run slack and where to keep the couplings taut. A case came under the writers' observation where a careful motorman handled a trip of 15 loaded wagons, while another motorman stalled with 10 wagons on the same stretch of track. This matter is a very important one from the mine owners' point of view. The cost of driving gangways and shafts is considerable, and any method which will allow of an increase in the quantity of coal which can be taken from a single opening in a given time, adds very materially to the mine owners' profits.

Lighting and Signals.—As the lighting of a mine is a comparatively simple matter, it is scarcely necessary to consider it here. The universal method is to light up all switch points, and only other places of exceptional importance. In large mines using a number of locomotives, an efficient system of signals should be used in the main headings. This should be an automatic block system. Mr. A. S. McAlister of Windber, Penn., has worked out such a system, using incandescent lamps between trolley and rails, which is working admirably.

Efficiency.—The question of efficiency, from a fuel standpoint. is of comparatively small relative value, as the difference in

actual cost in fuel in the different systems is insignificant, when compared with other expenses. Data available seem to indicate, however, that the all-electric systems lead in this respect. As regards the total commercial efficiency, including maintenance, labor, interest, and depreciation, there can be no doubt but that the compound electric system using polyphase and direct currents, will give the best results.

General.—The data and statements presented in this short paper are gathered from personal experience in the mines, from mine superintendents, and from student thesis work carried on under the supervision of The Pennsylvania State College. In writing the paper, it was not intended to give a complete detailed treatise on the use of electricity in mines, but to outline the most important conditions and facts bearing upon such utilizations.

Discussion.

Mr. Elmer A. Sperry:—What few remarks I have to make are in the line of a plea for simplicity in electric coal-mining installations. The class of labor employed in and about a mine is such that absolute simplicity is necessary. In regard to accidents, I might say that up to two years and a half ago, I think we employed only 250 volts. At that time there had been no serious accidents recorded except to mules. But lately since the 500-volt potential has been used, the danger to life has become an important factor and especially since the polyphase has been introduced. That is especially vicious, and using it as has been attempted in various cases, where the metallic parts of the machine are connected, the motor in some instances is secured solidly to the frames of the machines and no insulation is possible, the bare metallic parts being directly in contact with the operators. Bare wires have to be used as has been indicated in the paper and the main lines are very poorly insulated all through. The drippings and constant breaking away of the roof and tearing down the lines render the insulation at best very poor, making it almost impossible to operate with a polyphase. Sometimes the trouble occurs unexpectedly in the middle of a cut. The men that are engaged in the operation are often superstitious, and the moment they commence to feel the current they back away and it is almost impossible to get a machine stopped or started or dealt with in any sense. I touch upon these matters as showing the difficulties engineers working along these lines have to contend with. I should say that the troubles with the pumps and with the constant current motors are largely those of overload. The motors installed early in the art were usually too light for the work.

Sometimes there is an accumulation of water and the pumps are too small to handle it, and the motors too small for the pumps. Sulphur water is a bad thing for a pump. As Prof. Jackson says if a pump could be made to stand mine service it would be a help. If the pump is new it is easy of operation but the corrosion increases and presently the action of the sulphur on the pump makes it work twice or three times as hard, and the friction factor of a deep mine pump with no suction is always great. The instance which is mentioned in the paper where air had to be substituted for electricity, was probably the fault of the motor being altogether too light for the work. I think for this class of service where infrequent attention is given to the apparatus, large motors ought to be used and run at slow speed, and ought to be capable of doing the work easily. I think that the complexity and the added expense of the double system mentioned should be entirely done away with. I do not believe that with proper proportioning and designing, there exists the necessity of such a system. And as I said, the most absolute simplicity is the great desideratum.

Prof. W. S. Aldrich:—There is more promise of the application of electricity to coal mining in the development of new territory than of old. The prejudices do not exist in opening up new mines such as govern the continued use of equipment in old mines. Particularly important is the question of throwing aside old equipment, standing as it always does in the way of introducing the new electrical methods, however promising. While several changes in power transmission in mining operations have been brought about recently, they are chiefly confined to electricity and to compressed air. There is such a displacement going on, however, that at least one company has not installed a complete compressed air plant in the last four years. Electricity has been introduced successfully and it is practically the only means of transmitting power that has been introduced to develop abandoned coal mines. Lower veins have been thereby opened up that under the old methods were too expensive to work. Where working expense is limited, electricity is adopted. With regard to pumping, it is successfully performed by induction motors of course directly connected with centrifugal pumps or to triple-plunger pumps. The difficulties of electric pumping, however, are not entirely met by the induction motor, and one feature of this has been brought to our attention in this paper in the matter of standard sizes. There are engines in the market and there are pumps. There is no standard size of pump, no standard size of engine, of motor or of dynamo that will enable you to put such units together and have them work with best satisfaction. As long as each manufacturer has his own standards of fixed sizes there seems to be little hope of avoiding this difficulty. Professor Jackson says that in large pumps greater economy will be shown, but it is not stated whether these are to be of the ordinary direct-acting non-expansion type or whether they are to be of the more carefully designed triple expansion type. It is well known that the

ordinary direct-acting steam pumps consume anywhere from 120 to 300 pounds of steam per horse power per hour. The fact is that stationary compound and triple expansion pumps whether placed near or far away from the boiler, can be economically operated above ground; but these seem not to be capable in their usual arrangement below ground, of obtaining anything more than an economy from 20 to 30 pounds of steam per horse power per hour, corresponding to a duty of from 95 to 65 million foot pounds of work per million British thermal units. It would be a very poor electric installation that could not come up to that, even with a much smaller sized pump. It should be noted that the compound triple expansion pumps are in large units.

The largest of compressed air installations are now in use particularly in the anthracite fields where ventilation is so much needed. It has been found that mechanical circulation of air is better than to depend for ventilation upon air exhausts. In fact, it is better to get what you want directly than indirectly, better to have fans and a blower system than depend upon the exhaust from your air motors.

There is but one coal mining plant in West Virginia that is using at the present time a direct current 500-volt transmission, that of the Crozer Coal and Coke Co., Elkhorn, W. Va. The three-phase system has been installed, as far as the writer knows, at only five plants, namely: Columbia Gas Coal Co. at West Newton, Pa.; The Hutson Coal Compay, Deerfield, Ohio; J. W. Ellsworth & Co., Hartford, Ohio; Davis Coal and Coke Company, Thomas, W. Va.; Sterling Mining Co., Kennetta, Pa., and there have been no further alternating current installations since that of the J. W. Ellsworth & Co. eighteen months ago.

Mr. A. D. Adams:—It seems to me that in the eye of the average mechanical engineer the saving of a little or a great deal of copper occupies an undue space, and my observation of the application of electric power to industries is that there is too much of a tendency to run up the voltage. The difficulties of insulation are always with us, and we have sometimes found it better and often thought it better to put up with a rather larger investment in conductors, and a less investment in maintenance of insulation. I don't know much about coal mining but I think possibly that same state of affairs has a bearing upon that subject.

Mr. Sperry:—I think it would be safe to state an axiom that the miner's principal consideration of economy in the pump is to get there. He has to have something in this line that is absolutely to be depended upon and the matter of 60 pounds of coal or any other number of pounds referred to in this discussion is so far left by the other considerations that I think they need not be primarily considered in reference to mining pump installation. In some of the big anthracite mines it is simply a matter of shutting down the mine if water is not taken care of promptly. With the present scheme of "sumps" the matter of drowning out a pump is very unusual.

A paper presented at the 16th General Meeting of the American Institute of Electrical Engineers, Boston, June 28th, 1899, President Kennelly in the Chair.

AIR-GAP AND CORE DISTRIBUTION.

THE MAGNETIC FLUX AND ITS EFFECT UPON THE REGULATION AND EFFICIENCY OF DYNAMO-ELECTRIC MACHINERY.—II.

BY W. ELWELL GOLDSBOROUGH.

The exact analysis of problems, the solution of which depends upon a knowledge of the actual distribution of the magnetic flux in masses of iron, seems to have received scant attention if we judge the present development of the design methods in use, by the writings of Essen, Kapp, S. P. Thompson, Hopkinson, Elihu Thomson, Ryan, and many more of our engineers who have instructed us so well in other and intricate matters pertaining to the efficient construction of electrical machinery.

The only reference to researches bearing directly upon this subject known to the writer was made by W. M. Mordey during his discussion of Dr. John Hopkinson's paper on the "Propagation of Magnetism in Iron" before the *Institution of Electrical Engineers.* He stated that some seven or eight years ago he made a test with the object of finding whether the penetration in laminated iron took place evenly over the whole area of the sheet. Although the length of certain paths of the magnetic parts was necessarily greater than others, he found the magnetic density uniform. He accounted for it by assuming that any tendency to a greater density in one place would be counteracted by the relatively stronger permeability elsewhere.

I am not informed as to the character of the apparatus which Mr. Mordey used in obtaining his results, nor am I sure that he performed his experiments with the end in view of investigating the subject from the standpoint from which it is taken up in this

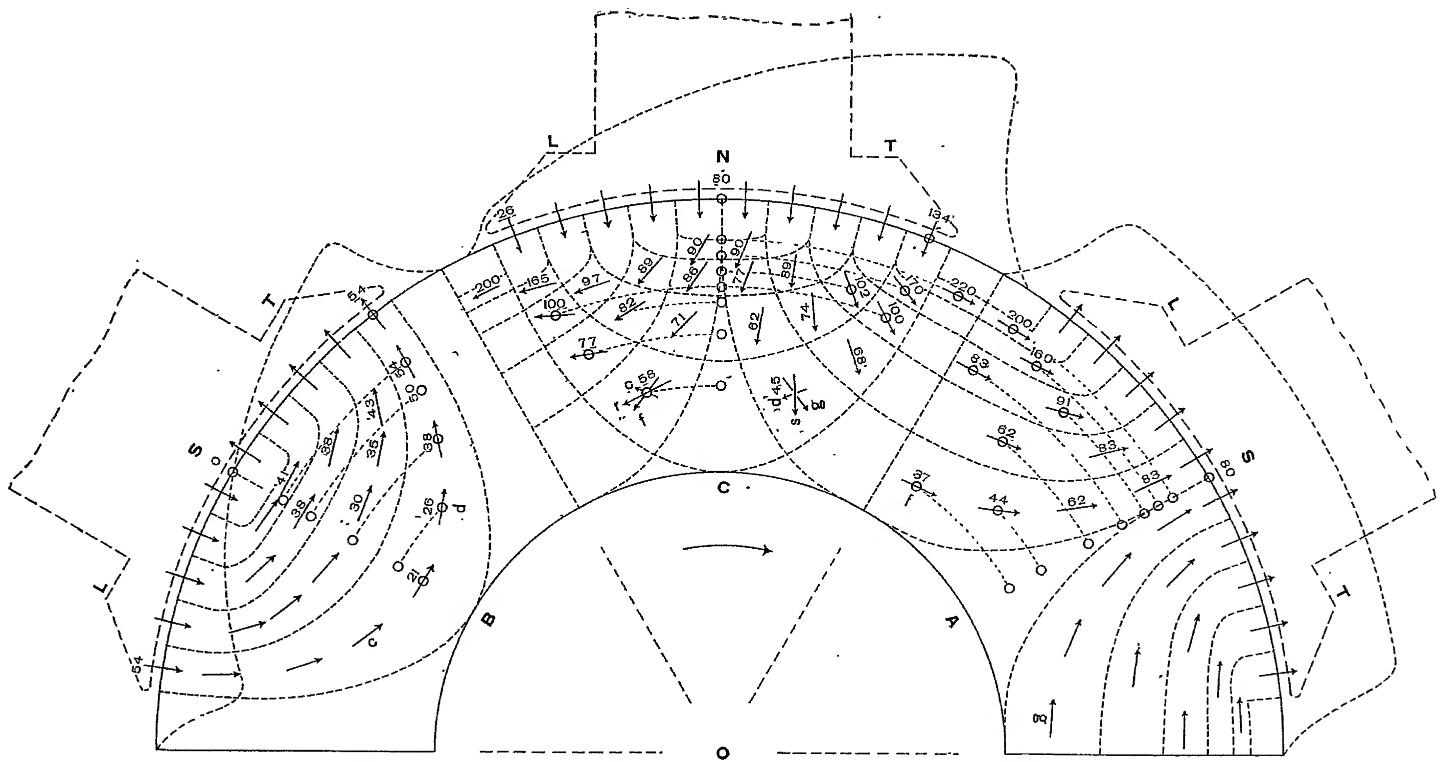


FIG. 1. Showing the calculated distribution of the magnetic flux in an armature core under three conditions. *A*—The distribution due to the field ampere turns acting alone. *B*—The distribution due to the armature ampere turns acting alone. *C*—Distribution due to the combined action of the field and armature ampere turns. The numerals give the values of the flux density in centigausses.

paper. Certain it is, however, that all theoretical considerations point to the fact that, as used in electrical apparatus, laminated iron is not in general so placed as to warrant the assumption that there is an even and uniform distribution of the flux in planes at right angles to the direction of the flux paths.

In many instances where the iron is not subject to cyclic fluctuations in the intensity of the magnetic lines, variations in the density in planes at right angles to the mean path of the flux are unimportant; but is this true in the cases where masses of iron and steel are made to revolve in strong magnetic fields? or, where fields of flux are induced in masses of iron by coils excited from sources of alternating E. M. F.?

In discussing this matter, suppose we consider the condition existing in the armature core of a six-pole, 110 K. W., railway generator, a half-section through the armature and field ring of which is shown in Fig. 2. I have shown in section A, of Fig. 1, by the dotted curve extending across the pole-face, the air-gap distribution of the flux at no load. It is practically uniform over the pole-face owing to the toothed armature construction and the relatively narrow clearance space. Inasmuch as only a little over one per cent. of the total field ampere-turns are used in forcing the flux through the armature core and 73 per cent. is needed to force the flux through the double air-gap, the assumption that the surface of the armature under any pole-face is an equipotential area is admissible. The problem of determining the exact position of the flux-paths, and the density at various points in the plane of the section then resolves itself into a problem of dividing that portion of a lamina that lies between the center lines of two adjacent poles into paths of equal magnetic reluctance connecting equipotential surfaces.

The pole-face over section A, of Fig. 1 has been divided parallel to the shaft, into 10 equal strips, and these have been projected upon the armature surface as shown. The dotted lines joining the pole-faces through the armature show the dividing lines between the paths of equal reluctance. These paths have been determined by first equalizing their reluctance on the basis of a permeability of the iron of unity, and then making the necessary connection for the variations in the permeability of the iron with the varying densities by successive trial. Since each of the paths has the same reluctance, and is influenced by the same M. M. F., acting at its terminal points, the same

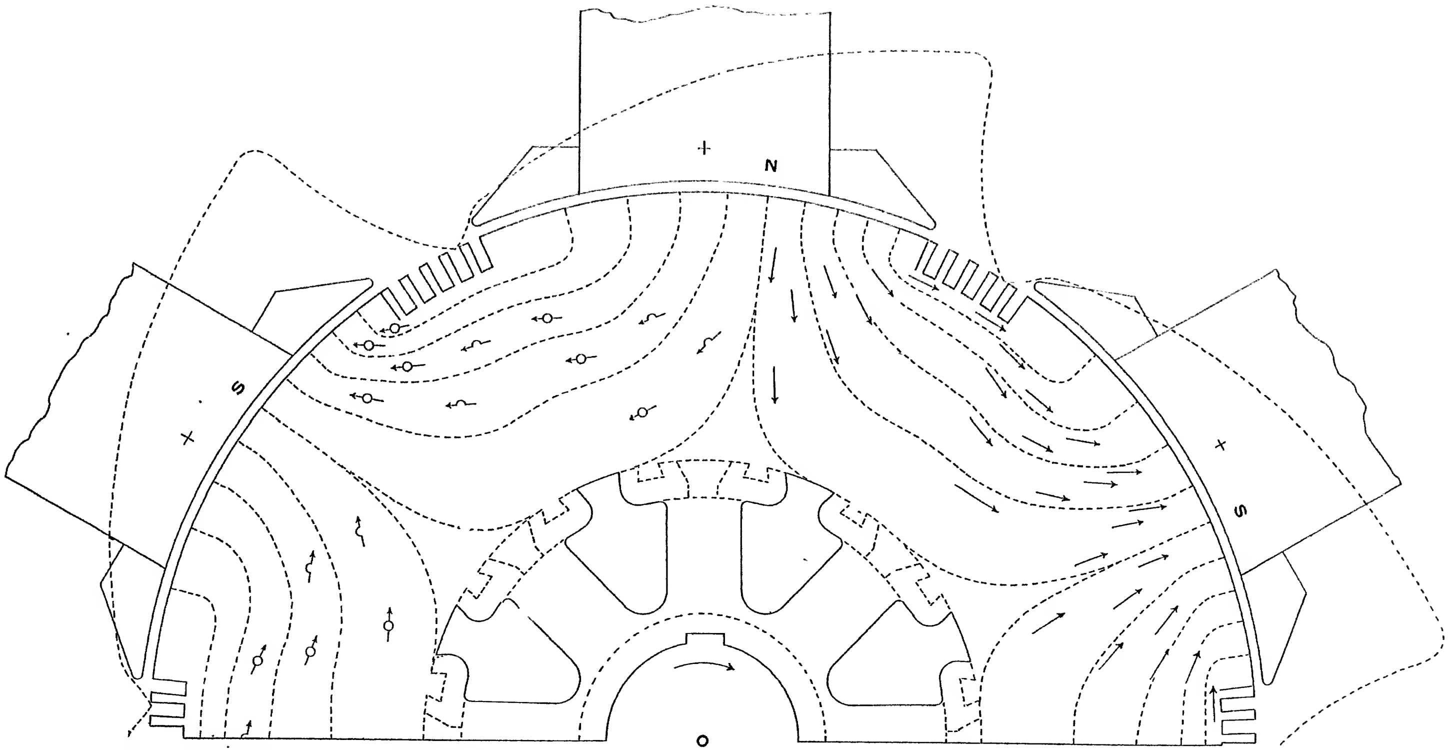
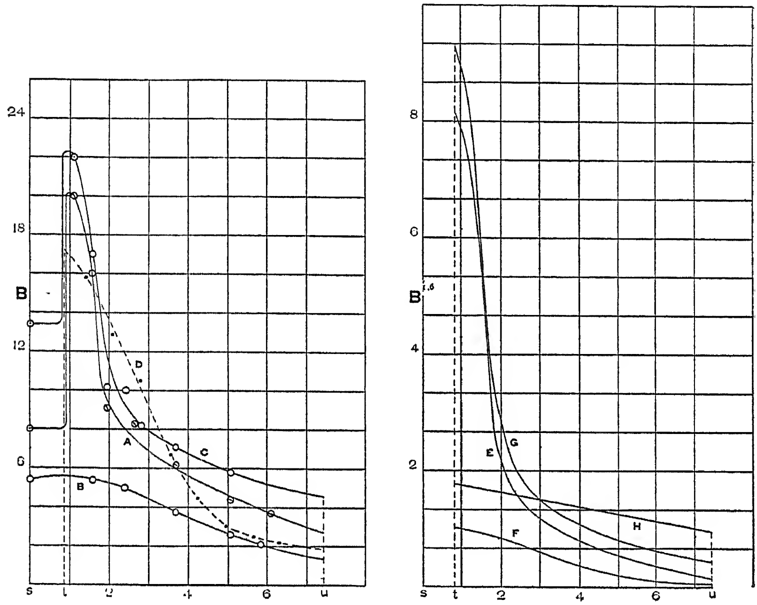


FIG. 2. Flux distribution in the core of an armature under full load conditions. Each path between pole faces as defined by the dotted lines, embraces the same number of gausses,

number of webers passes through each path and the number of gausses at any point on the center line of a path is equal to the flux per path in webers divided by the width of the path in centimetres at the point considered. The arrows drawn in section A, show the direction taken by the flux at as many points, and the numbers indicate the densities at the center of the arrows in centigausses. The magnetic density in the iron near the inner surface of the core on the dotted line between sections A and C is a little less than 3,000 gausses, while the density in the iron just below the teeth on the same line is a little over 21,000



PART 1. PART 2.

FIG. 3. Core Distribution Curves and Hysteresis Core Loss Curves.

gausses. At no load the flux paths are symmetrical about the section lines, except in so far as they are distorted by being slightly depressed under the leading pole tips L and raised under the trailing pole tips T as each molecule of iron is carried through the cycle of the hysteresis loop by the rotation of the armature. The arrows passing through the small circles indicate the points of maximum density in rings having radii equal to the distances of these arrows from the center O. In other words a molecule of iron is subjected to the greatest

magnetic stress when it passes under one of these arrows. The arrows are supposed to maintain fixed positions relatively to the poles, while the armature core rotates. Projecting the maximum density points of section A circumferentially on a radial line, and transferring them to Fig. 3, we obtain the curve A, Fig. 3, part 1. This curve shows the maximum core densities occurring in the iron at points having different radial distances from the center of rotation. The ordinates are expressed in kilogausses and the abscissae in inches. The distance $(s\text{-}t)$ is the depth of the slots; the distance $(t\text{-}u)$ the depth of the core iron below the slots. The magnetic density of 8,000 plotted over $(s\text{-}t)$ is the average density in the teeth and slots; the actual maximum density in the teeth at no load being 20,600 gausses. In laying out the equal flux paths of Fig 1, allowance was made for the difference in the actual magnetic density in the iron of the teeth and the average magnetic density in the teeth and slots, by reducing the depth of the slots and increasing the length of the clearance space by an amount equal to the length of an air path having a width equal to the polar arc, and a reluctance equal to the reluctance of the path through the teeth and slots.

To determine the hysteretic loss occurring in the part of the core below the slots from the distribution curve A of Fig. 3, the ordinates of the curve A were raised to the 1.6 power of the density which they represent, and then reduced in the ratio of their distance from the center of rotation to the distance of the point t from the center of rotation. In this way the curve E, figure 3, part 2, was obtained, the area of which is proportional to the hysteretic loss in the core. The correction for the difference in the distance from the center o of the successive points of the curve A is necessary, as the volumes of the rings which the densities influence vary 54 per cent. between the outside and inside rings. We therefore find that with the distribution given in section A of Fig. 1, the core loss due to hysteresis will be 663 watts.

If we follow the usual practice[1] in making these calculations, and assume that the flux in passing between the poles spreads

1. Dr. John Hopkinson, "Philosophical Transactions," of the Royal Society, May 6, 1886.

Gisbert Kapp, "Dynamos, Alternators and Transformers," p. 242.

S. P. Thompson, "Dynamo-Electric Machinery," p. 176.

Ryan and Macomber, "Sibley Journal," Jan., 1897, p. 125.

evenly over the core, the density in the core will be 7220 gausses and the core loss 492 watts, than which the value given above is 35 per cent. greater. (See curve H.) Apparently, therefore, if we admit the basis upon which these calculations have been made to be correct, the methods at present in use give erroneous results.

The discrepancy between the two methods, however, is greater than the considerations so far presented would lead us to suppose. In general it is assumed that if the total effective field ampere-turns impressed on the magnetic circuit are kept at a constant value, *i.e.*, if the difference between the armature back ampere-turns and the total impressed field ampere-turns is kept at a constant value, the armature losses, in the part of the core that is below the slots, will remain constant in value from no load to full load.

With a view to investigating this point, suppose we consider the effects produced by the cross-magnetizing armature ampere-turns when the field circuit is open and the armature coils are separately excited. Under these conditions, as shown in section B of Fig. 1, a field will be set up through the trailing pole-tip T, across the air-gap; through the armature core; and back across the air-gap, up into the leading pole tip, L. The ampere-turns acting to set up this field, will be zero about the center line of the pole-face, but gradually increase to a maximum under the pole-tips. The M. M. F. acting on the core paths between the two halves of the pole-face, will be proportional to the ampere-turns, and if paths be traced through the armature core, connecting points on either side of the center line of the pole-face and having a constant reluctance, the average flux density per path will be proportional to the M. M. F. impressed upon each path, and a balanced system of forces will be established in the armature core. The paths traced in section C have been calculated, with due reference to the permeability of the iron at different densities, to fulfil this condition; and the densities as indicated by the numbers over the arrows, have been determined as being the actual densities set up in the core by the cross-magnetizing ampere-turns. Owing to the fact that the M. M. F. acting on the longest path has the greatest value, the arrow points of maximum circumferential density all fall in this path. When these points are projected on the center line, and the values they represent transferred to Fig. 3, we get the curve B

which gives the values of the maximum densities through which the iron passes as it is revolved under the poles. In calculating the hysteretic losses that will take place in the core with separate armature excitation, we get curve F, obtained from curve B in the same way that curve E was obtained from curve A, and find that the core losses will amount to 174 watts.

Now to determine the distribution in the core at full load, when the total effective field ampere-turns are kept at the no-load value, we must combine the results already obtained and recorded in sections A and B of Fig. 1. This was done, and each of the arrows of sections A and B were properly transferred to section C, and the vector sums taken. As examples, vectors *f* and *c* were combined as shown to obtain vector *r*, and vectors *g* and *d* were combined to obtain vector *s*. Again it must be noticed, that vector *f* is numerically equal to vector *g* and vector *c* is numerically equal to vector *d*, but owing to the difference in the angular positions they assume when combined, vector *r* has a value 29 per cent. greater than the value of vector *s*. It is also interesting to notice that as the load comes on the machine, the density at the point *f* gradually increases, with constant effective field excitation, from 4400 to 5800 gausses at full load; and that an increase of 32 per cent. in the flux density at this point, has produced an increase of 55 per cent. in the core losses per unit volume for all iron at a distance *f-o* from *o*.

These same considerations apply to all the points in the armature core to a greater or lesser degree, and result in giving an entirely new distribution of the flux in the core. The points of maximum radial or circumferential density are also changed, and we find them located under the trailing pole-tip T of section C, in the upper part of the core, and under the leading pole-tip L, in the lower part of the core. If we project the maximum density points upon the center line and transfer them to Fig. 3, we get now the curve C, the curve of maximum core densities at full load. Calculating the hysteretic losses, we get the curve G, and finally determine the full load loss to be 830 watts. Between no load and full load, therefore, while the total flux entering the armature per pole is maintained at the same constant value, the hysteretic loss in the core would seem to increase from 663 to 830 watts, or 25 per cent. And if the final value of 830 watts is compared with the uniform density value of 492 watts, we see the discrepancy in methods is

really much greater than at first seemed probable, being 69 per cent. instead of 35 per cent.

Of course these values refer only to the losses in the solid part of the core below the teeth. The hysteretic loss in the teeth at no load is 132 watts, and at full load 246 watts, owing to the change in the density under the strong or trailing pole tip; and an additional 27 per cent. must be added for eddy-current losses. The total armature core losses at no load are, therefore, 1000 watts and at full load 1370, and the real increase in the total core losses from no load to full load is 37 instead of 25 per cent.

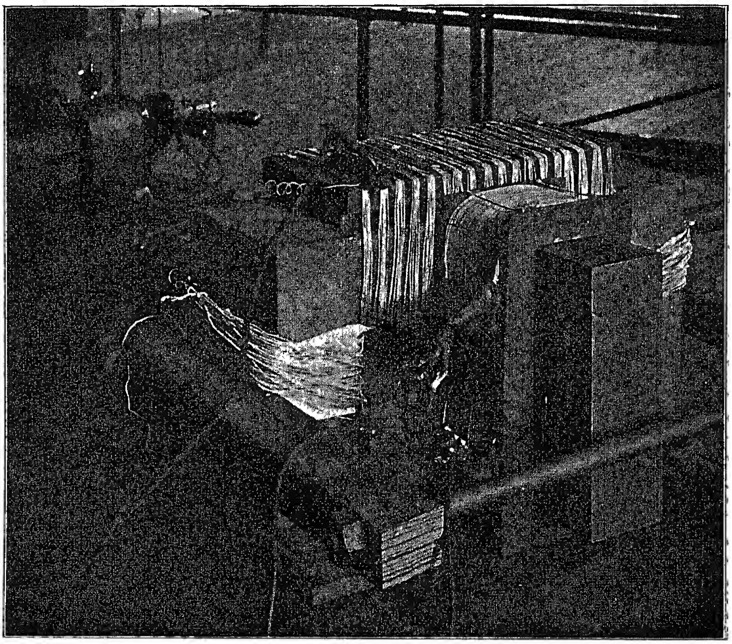
The increase in the core loss with the load which these calculations show, probably accounts in part for the failure of many machines to come up to the expectations of their designers, and certainly presents an interesting field for speculation. With each change in the depth of the core, the core distribution of the flux changes. With each modification of the percentage of the armature covered by the poles it changes. With each modification of the armature winding, the distribution of the flux in the core changes. All these matters have a direct bearing upon the core losses, and are interesting as problems.

In Fig. 2 the results obtained in connection with Fig. 1 are displayed. The equal flux paths traced between the poles have been carefully located with reference to the full load flux distribution, and without reference to the direction of the vectors. It will be seen, however, that the black vectors on the right, which are the same as those of section c, Fig. 1, follow quite closely the direction of the paths as is to be expected. On the left of Fig. 2 the trace is shown of only the maximum density vectors, to the end of bringing out more clearly the effect upon the core-distribution of the armature ampere-turns. It will be seen that they have the effect of forcing the flux toward the bottom or inner periphery of the core under the leading pole-tips and of crowding it upwards toward the outer periphery of the core under the trailing pole-tips. Accordingly, the maximum density curve c of Fig. 3 has an area a number of per cent. greater than the area of a similar curve plotted from densities taken in a plane at right angles to the direction of the flux. In other words, the area of the curve c represents a greater amount of flux than really exists in the armature core.

The regulation of the machine here discussed is modified to

some extent by the effect of the saturation that occurs in the teeth and cast-iron pole shoes, so that the full load air-gap distribution is better than that shown in section c of Fig. 2, but for the sake of simplicity in taking up the subject for discussion, all modifying factors of this character have been eliminated.

With the end in view of obtaining experimental evidence of the correctness of the method of determining core losses that has been outlined above, two of my students, Messrs W. T. Hensley and E. B. Kirk, constructed a special piece of apparatus. As



View of Apparatus.

shown in the illustration contained in this paper it is an electro-magnet, resembling as much as possible one pair of poles of a multipolar dynamo with a section of the armature. The armature is of rectangular form. As the flux divides to right and left under the pole face of a multipolar machine each pole of the magnet was made to represent half a pole of a dynamo.

The magnet is built up of thin plates of transformer iron, .015″ thick. Working drawings of the magnet and its parts are shown in the plates following.

The core and armature are made up of 180 of these laminations held by two side plates, each of the same surface dimensions, but 3-16″ thick. The whole is fastened together in both

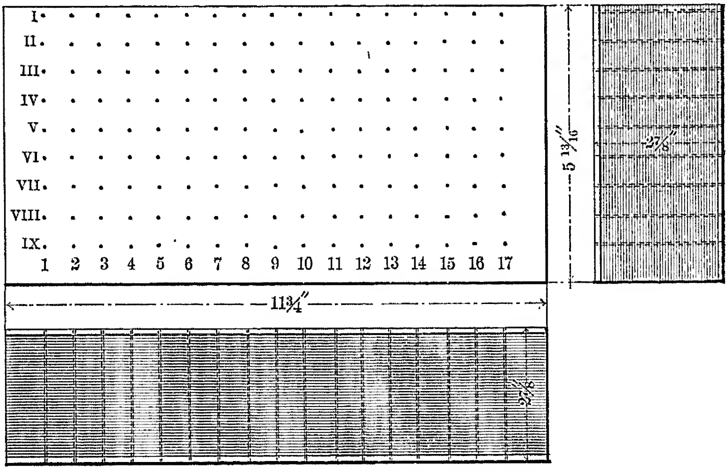


FIG. 4. Armature of apparatus used to determine the distribution of the magnetic flux in laminated iron cores.

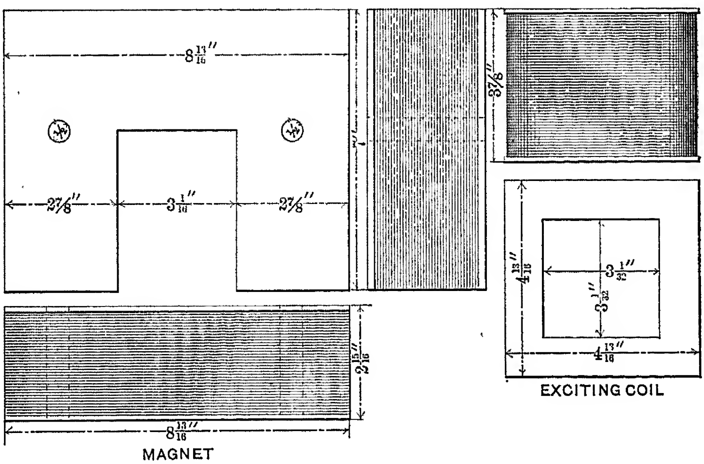


FIG. 5. Field yoke of apparatus used to determine the distribution of the magnetic flux in laminated iron cores.

armature and core by means of rivets.

A series of holes were bored in the armature, perpendicular to the side faces. They are .089″ in diameter and placed in rows

at right angles to each other, 5-8″ apart either way. Exploring coils of five turns each were wound in each pair of holes, making 29 conductors in each pole. Double silk covered wire was used.

Before winding the armature it was placed in a coil oven and baked for twelve hours in order to rid it of all moisture. To insulate the sides of the armature and to keep the ends of the coils from coming in contact with the armature iron, side plates of wood fibre were put on, holes being bored in them, corresponding with those in the armature. The winding was then made by threading the holes with the wire by means of a long

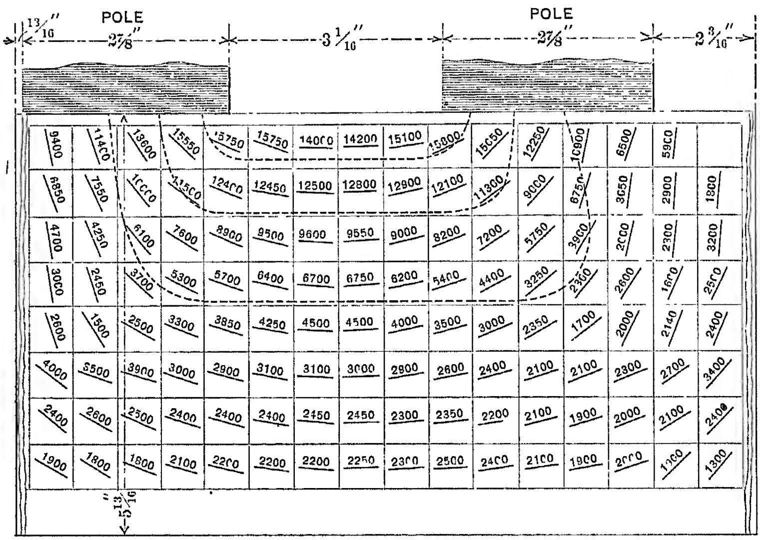


FIG. 6. Chart showing the direction and intensity of the armature flux developed by poles placed at either end of the armature core. Length of single airgap, about .015″. Field ampere-turns, 1405.

slim needle. Each coil was tested for grounds and short-circuits when the winding was completed.

The field winding of the magnet consists of eight coils which were so designed that when placed in a series the magnet could be energized from 110-volt mains and when connected in parallel it could be used with as low a voltage as 7.5.

As it was very necessary to know the exact area enclosed by each exploring coil, the distance between the edges of the holes was accurately measured. The exact area was then determined, where the holes were not parallel, by finding the area of the par-

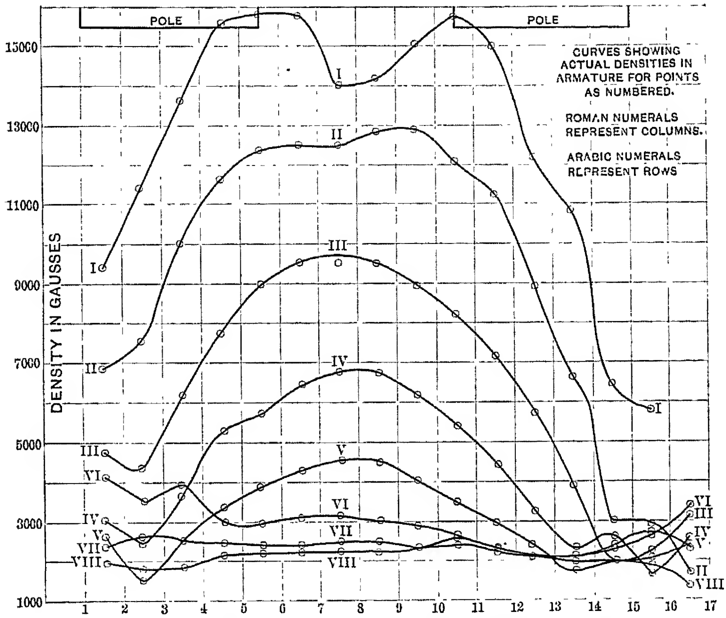


FIG. 7. Distribution of flux in armature when excited by poles placed at either end. Length of single airgap about .015″. Field ampere-turns, 1405.

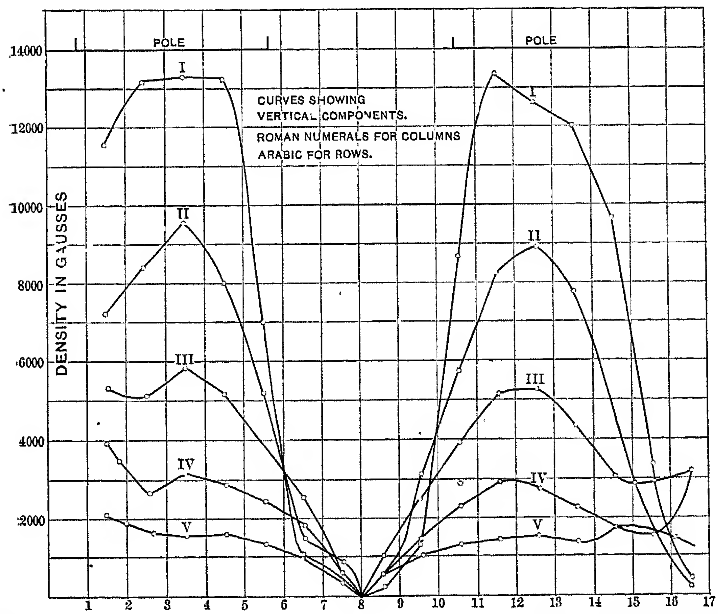


FIG. 8. Vertical components of flux in the armature when excited by poles placed at either end. Length single airgap, about .015″. Field ampere-turns, 1405.

allel part and the area of the trapezoid and taking their sum. The holes were parallel to a depth of 1.72″, but for the remaining distance the area was a trapezoid. Knowing the area enclosed by each coil, corrections were made for the readings from each coil.

The armature was made deep in order to magnify the distortion of the lines of force which it was thought would occur. The distribution was studied in the armature alone as the distribution in the armature core of a dynamo is the important element in calculating the core losses, whereas the field core distribution is unimportant.

The terminals of the exploring coils were brought up to

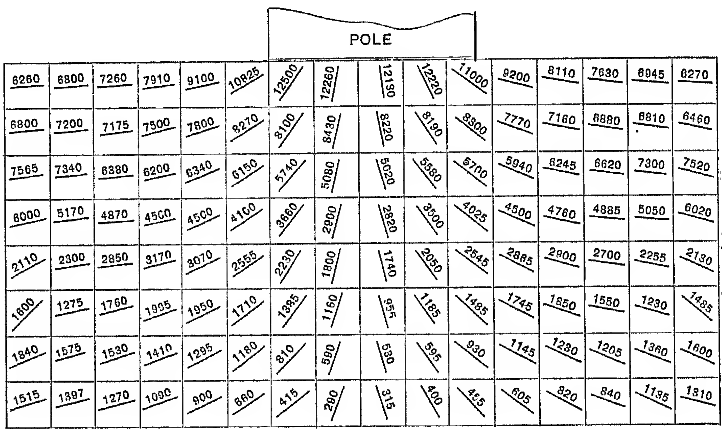


FIG. 9. Chart showing the direction and intensity of the armature flux, when one pole is acting at the center of the armature. Airgap, .0612″. Field ampere-turns, 1875.

mercury cups in a board above the armature. These were arranged in such a way that any coil could be put, when desired, in series with a ballistic galvanometer, the terminals of the galvanometer being simply placed in the two mercury cups containing the terminals of the coil.

Since the coils were wound in planes perpendicular to each other they afford a means of determining the horizontal and vertical components of the density. Hence, the vector sum of the components at a given point is the actual density at that point and the direction of the vector resultant is the direction of the flux at the point.

The intensity of the magnetism at the center of the area enclosed by each four holes was determined by taking the mean of the readings from the (n)th and (n–1)th vertical coils and the mean of the readings of the (m)th and (m–1)th horizontal coils of the (y)th vertical and (x)th horizontal rows. The vector sum of these means gives the intensity at the point considered, and unless the curves for the horizontal and vertical components are extremely irregular from point to point, the method gives a very close approximation to the correct value.

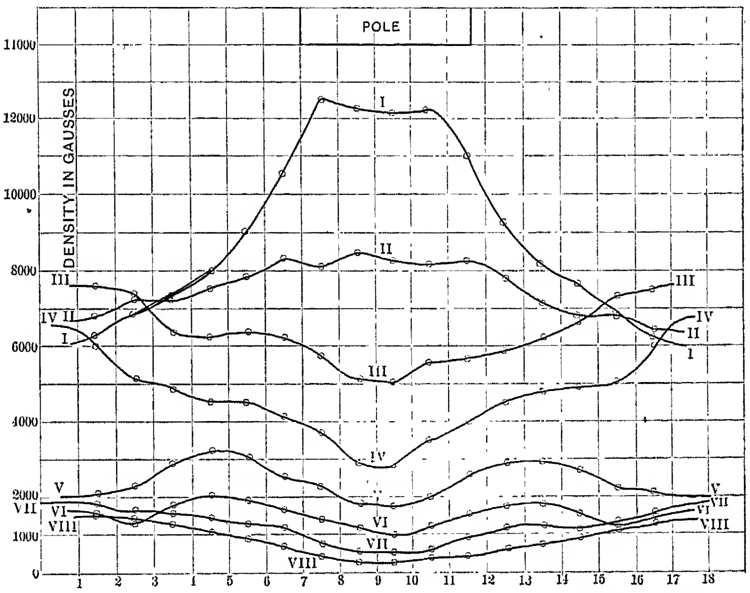


FIG. 10. Curves showing actual density in the armature, with one pole at the center of the armature. Plane of field yoke at right angles to plane of armature laminae. Air-gap, .0612″. Field ampere-turns, 1875.

The width of the face of the armature in contact with the poles was practically the same as that of the poles, hence the component of the magnetism perpendicular to the side faces was taken as zero, since the sides of the armature are parallel also. Correction was made for the distortion due to the holes containing the exploring coils as follows:

The actual area enclosed by a square having for its vertices the centers of four of the holes was found and the side of the equivalent square was determined. Then the ratio of the actual

distance between the inner sides of the two holes from one another to the side of the equivalent square was taken as the correcting multiplier for the holes.

Correction for lamination was made as follows:

Weight of armature if solid, 24655.3 grams with wrought-iron at 480 pounds to the cubic foot.

Actual weight of armature, 21437.64 grams. The ratio of these weights, .87 is the proportion of iron in the armature.

The gentlemen who constructed this apparatus also obtained a series of experimental records under various conditions of working, and their results are shown in part, in Figs. 6, 7 and 8.

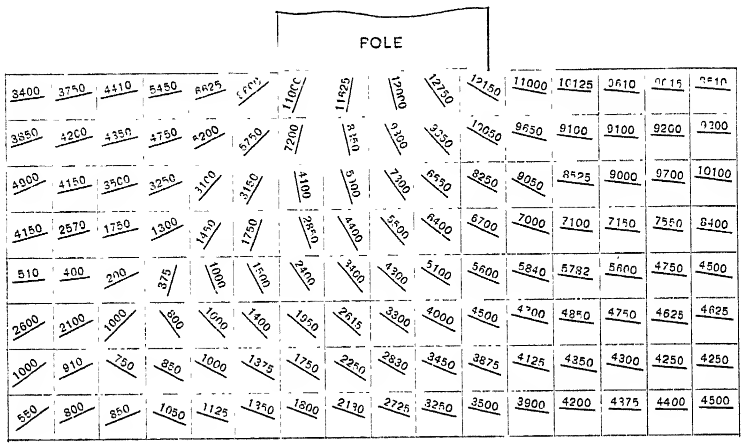


FIG. 11. Chart showing the direction and intensity of the armature flux, when one pole is acting at the center of the armature and influenced by the armature cross-magnetizing turns. Air-gap, .0613″. Field ampere-turns, 1875. Cross-magnetizing ampere-turns, 540.

The experimental work was completed by Messrs. F. Maze and O. Williams, during the past spring, and some of the results obtained by them are shown in Figs. 9, 10, 11, 12, 13 and 14.

The results, as they are presented, indicate so clearly the conditions which obtained in each case, that it is hardly necessary for me to add a word in explanation.

Fig. 8 is directly comparable with section A of Fig. 1. It represents the conditions existing in a machine in which the poles cover 65 per cent. of the armature, however, instead of 80 per cent., as in the case of Fig. 1, and differences are noticeable accordingly. For instance, the curve of maximum density

distribution for Fig. 8, is plotted as curve D, Fig. 3, and it is seen that the changes in the flux distribution are hardly so abrupt as in the case of curve A. The ratio of the maximum to the minimum density of curve D, is 9, while the ratio of the maximum to the minimum ordinates of curve A, is 7. The ratio of the hysteretic loss that would occur in an armature having a core distribution like that of Fig 8, to the hysteretic loss calculated on the assumption of a uniform density in the core, is 1.23.

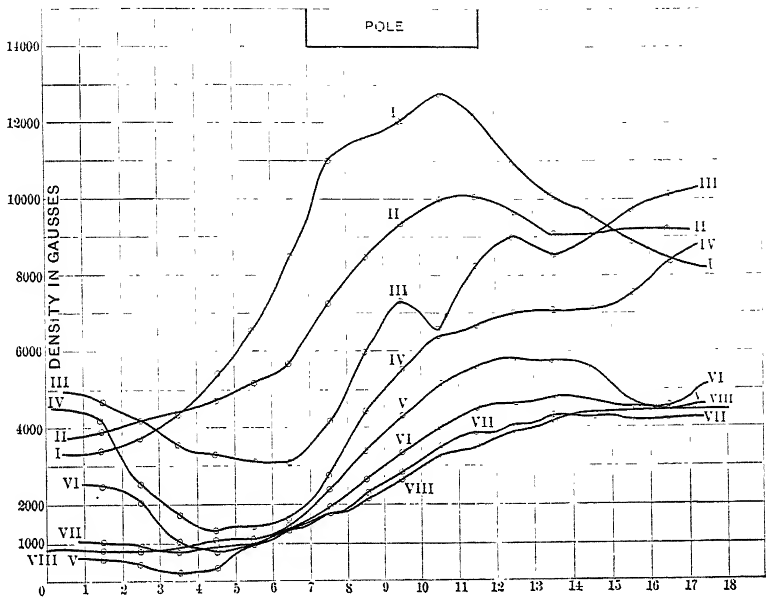


FIG. 12. Curves showing actual densities in the armature core. with one pole at center of the armature, and both field and armature-cross-magnetising coils excited. Airgap, .0613″. Field ampere-turns, 1875. Armature ampere-turns, 540.

Therefore there is a difference of 23 per cent. in the experimental case, as compared with 35 per cent. in the calculated case. This difference is due to the fact that the shortest path in Fig. 8 is proportionally longer than the shortest path in section A, of Fig. 1, and to the fact that the armature of Fig. 8 has an infinite radius, and therefore the areas of least density rank equally with the areas of high density in calculating the hysteretic losses, where, as in Fig. 1, the areas of least density are only 54 per cent. as effective as the areas of high density.

The trace of the equal flux paths in Fig. 8, is made by the dotted lines connecting the pole-faces.

The curves of plates 7 and 8 are also very instructive in throwing light upon the matter. They bring out clearly the crowding of the lines of force together as they pass the corner positions of the poles, making the maximum density occur at the sides, rather than at the mid-point between the poles.

The results pictured in the figures so far discussed, were obtained with the two poles of the yoke acting on the armature section as shown, and without any effort to produce cross-magnetizing armature effects.

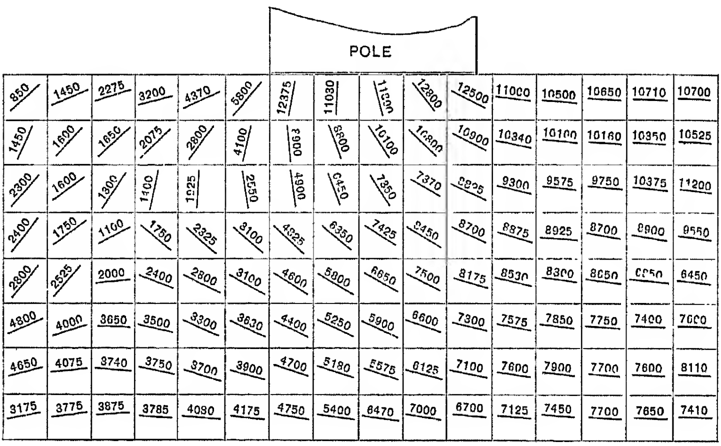


FIG. 13. Chart showing direction and intensity of the armature flux, when one pole is acting at the center of the armature, and the armature is powerfully cross-magnetized. Air-gap .0613″. Field ampere-turns, 1875. Armature cross-magnetizing turns 1170.

In the succeeding figures the plane of the poles is at right angles to the plane of the armature laminæ. The armature is extended by side bars and a back bar, into a rectangular construction across which the pole yoke bridges. It is this arrangèment of the apparatus that is shown in the illustration of the apparatus.

Figs. 9 and 10 show the character of the flux distribution under the pole-face when the field coils are acting alone. In this case the symmetrical arrangement of the curves indicates that the flux divided about evenly, and that the return paths to right and left have about the same reluctance. It is noticeable

here as in Fig. 8, that the maximum density occurs at the pole corners, but it falls off very much more rapidly between the poles, as the arrangement of the apparatus admits of only about 14 per cent. of the armature surface being covered by the pole-faces. The bunching of the curves I, II, III and IV, at the sides, and of the curves V, VI, VII, and VIII at the lower corners of Fig. 10 is due both to the presence of the rivets at the sides which hold the armature stampings together, and to the fact, as shown by a special test, that the magnetic joints between the armature

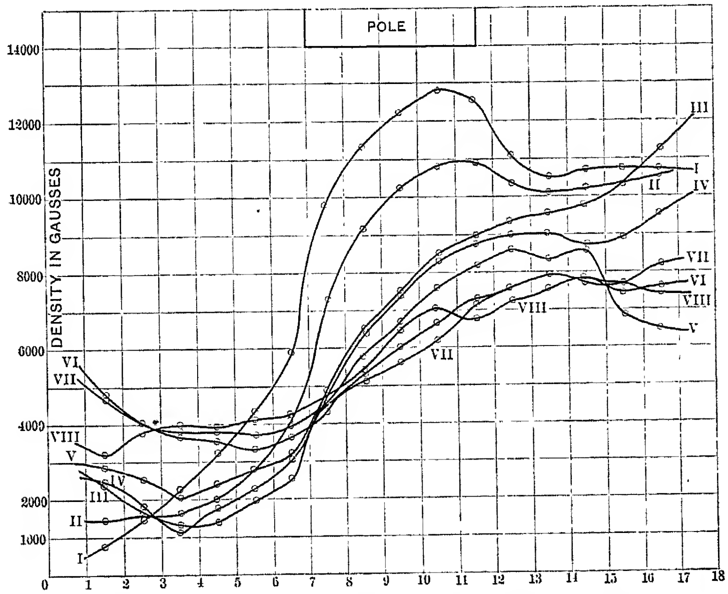


FIG. 14. Curves showing actual densities in the armature, with one pole at its center, and both field and armature-cross-magnetizing coils excited. Airgap, .0613. Field ampere turns, 1875. Armature cross-magnetizing ampere-turns, 1170.

and end bars was better at the top and bottom than at the middle of the ends of the armature.

In Figs. 11 and 12 the effects of cross-magnetizing currents impressed upon the armature rectangle by means of coils wound around the armature and evenly distributed along its surface are very well exhibited. The armature ampere-turns were arranged to act in one direction only so as to create a field in the armature rectangle without influencing the field yoke. The effect (see Fig. 12) was to markedly distort the core distribution in what

would be the direction of rotation in a dynamo; to weaken the field under the leading pole-tips and to throw the flux towards the bottom of the core. Under the trailing pole-tip just the opposite effect is noticeable, and the special features discussed in connection with section c, of Fig. 1, are all present here. In Fig. 11, the arrows bring out strongly the directions taken by the lines of force issuing from the pole-face. Inasmuch as the pole flux is compelled to separate equally to the right and the left the superposition of the horizontal components of the armature flux upon the pole-field vectors is well illustrated, and a strong similarity can be traced between the effects shown here and those previously calculated.

By doubling the cross-magnetizing effect of the armature ampere-turns all of the effects just noticed were brought out much more strongly. From Fig. 14 it will be seen that the flux density at the lower right hand corner of the armature was raised to two-thirds of the value of the flux in the upper courses, and that on the left hand side the flux has been thrown into the lower courses to so great an extent that the density is four times greater at the bottom of the armature than it is in the left hand upper corner. In this latter case the total flux permeating the armature core is about 2.2 more than that set up by the field ampere-turns acting alone, or the armature ampere-turns set up through the armature rectangle, a field equal to 1.2 times the flux set up in the field coils by the field ampere-turns. The conditions here present are similar to those existing in the older types of dynamo machines in which the field under the leading pole-tips became zero or was reversed by the cross-magnetizing effect of the armature ampere turns.

When the armature ampere-turns were alone excited it was found that the distribution of the flux over a section of the armature core, taken at row number 9 or 10, and at right angles to the direction of the flux, was perfectly uniform.

Purdue University,
Lafayette, Ind.
June, 1899.

DISCUSSION.

MR. STEINMETZ:—This paper of Prof. Goldsborough appears to me a very interesting investigation on the topic of magnetic flux distribution in dynamo electric machines, and I believe a very valuable contribution to our knowledge on these subjects. Obviously the paper does not intend to give final numerical values, but merely to draw attention to some effects existing to a greater or less degree in the armatures of electric machines, consisting essentially in an unequal distribution of the magnetic flux, at no loads, and a change of the distribution of flux with changes of loads, both effects acting to increase the loss of power in the armature over that calculated under the assumption of uniform density.

Let us see, however, what conclusions we can draw herefrom. As you know, it is customary to calculate the magnetic core losses in such machines under the assumption of uniform magnetic density, and then to multiply the calculated value by an experimental factor, which makes an allowance for losses in the metallic parts of the armature structure which are near the magnetic field and are necessary for mechanical construction. If now with the constants used in actual machines, the effect consisting in the increase of the core loss due to unequal distribution of flux is considerable, it would follow that with increasing thickness or depth of the armature core, the factor would increase, the distribution of flux becoming more unequal. Experience has shown, however, that those machines in which the core loss is a very large part of the total loss, and can be thus accurately determined, no effect of this kind appears of a magnitude sufficient to make itself felt without special investigation, so that it appears that with the relative dimensions used in most machines the effect is of small magnitude, although undoubtedly existing to some extent.

As well pointed out in the paper, the effect of unequal distribution of flux at no loads, depends on the constants and relative dimensions of the machine, as the depth of the armature core and the distance between the pole corners and the pole arc. Machines with the armature iron extending down to the shaft, and poles covering 80 per cent. or more of the pole arc, will show the effect more than machines having shallow armature cores and long distance between the poles, in which latter no notable effect due to an unequal distribution of the magnetic flux should be expected.

Coming now to the second point, the increase of the inequality of the distribution of the magnetic flux with the increase of load, this effect naturally depends on the unequal distribution at no load. In those machines where the flux is uniform at no load, the change in the load will not change the distribution noticeably, while in machines with very irregular flux distribution at no load, considerable changes with the increasing load may be expected.

Furthermore, however, this change of distribution with the load depends upon the relative proportion of armature reaction, that is, magneto-motive-force per pole of the armature, to field excitation; that is ampere-turns per field pole, or rather ampere-turns consumed by the main magnetic flux in armature core, teeth and air-gap.

In machines of large armature reaction, this effect is obviously greater. It is due essentially to the variation of the M.M.F. of the armature which differs from point to point, due to the distribution of the armature M.M.F. over the whole surface of the armature. Thus this effect does not exist at all in those machines where the armature M.M.F., that is, the armature conductors are massed in one slot, or two slots in a quarter-phaser, three slots in a three-phaser.

In these machines the resultant of the M.M.F. of the armature and that of the field, and thus the total magnetic flux and the distribution of the magnetic flux in the armature core is the same at no load as at full load, assuming the same induced E.M.F. In these machines you will find no increase of the density or change of the distribution of magnetic flux, outside of a magnetic flux of greater or less magnitude which passes in a local circuit at the armature face across the opening of the slot, due to the armature self-induction, but which does not increase the flux in the armature core, and thus usually introduces a relatively small load loss only.

What I want to bring out is, that this paper, while it is extremely valuable, must not be taken as giving exact values, since in this case it might be misleading by letting the reader believe that there is necessarily a very considerable and serious increase of core loss from no load to full load, which is not necessarily the case, as such increase depends entirely on the type and the constants of the machine. But the paper gives, as I said before, very valuable means for further thought and investigation of this feature which has been investigated very little compared with the investigations made in other directions, and for this purpose the paper is of great interest and value.

MR. BLOOD:—I wished to say quite a bit on this subject but I will simply make one or two statements. One is that I find in this connection the difference is not so much as would be expected. It will be found that although between no load and full load there is a large difference in variation in density and movement of the lines; when the amount of iron is considered, the total watts is not what might be expected from the ratio of densities. Another point, the effect is greater where the pole face density is small. Where it is near a hundred thousand lines per square inch the variation does not appear to be so much between no load and full load.

PROF. GOLDSBOROUGH:—I will only say that Mr. Steinmetz has touched upon everything that I might add in connection with the paper. I think you will appreciate the fact that in selecting

the problem, of a machine having a very deep core and 80 per cent. of the armature covered by the poles, I have taken a case which emphasizes the flux distortion. The differences shown between the two methods are not really as important as they may at first appear. For instance, a variation is shown of 45 per cent. in the core loss. But the total hysteresis loss is only one per cent. of the output of the machine, and therefore this increase represents a difference of but a fraction of a per cent. in the efficiency of the generator. It is more a matter of technical interest than of vital practical importance.[1]

THE PRESIDENT:—The next subject is a paper on "Operating Costs of Horse and Electric Delivery Wagons in New York City." by George F. Sever and Robert L. Fliess.

The Chair suggests, that the succeeding paper by E. A. Sperry being on an allied subject, it may be advantageous if the authors are willing, that the discussion on these two papers should be combined.

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1. Loss in the core below the teeth by uniform density method, 492 watts at full load.

Loss in the core below the teeth by the actual flux distribution method, 830 watts at full load.

Loss in the teeth by both methods, 246 watts at full load. Therefore:—

$$492+246=738 \text{ watts.}$$
$$830+246=1076.$$
$$1076-738\div738=45 \text{ per cent.}$$

A paper presented at the 16th General Meeting of the American Institute of Electrical Engineers, Boston, June 28th, 1899, President Kennelly in the Chair.

OPERATING COSTS OF HORSE AND ELECTRIC DELIVERY WAGONS IN NEW YORK CITY.

BY G. F. SEVER AND R. A. FLIESS.

During the last three years many descriptive articles relating to the automobile, have appeared in the technical press, but up to the present time, there has been published no definite data which might be used to indicate whether or not electric operation possessed any advantages. Hence both the general, as well as the technical public, could form no definite opinion as to the benefits to be derived from the use, in any particular class of service, of either an electric or a horse system.

The purpose of this paper is to present the results of an investigation, carried on during the past year in the city of New York, of the operating costs of the horse and electric delivery service, as at present instituted by the large department stores. This investigation formed part of a graduation thesis in the Electrical Engineering Department of Columbia University.

The present status of the art does not permit of an exhaustive comparison, as some of the data now presented will probably be entirely altered by the rapid developments which are taking place, the art progressing quite similarly to that of the electric railway. That which can be done most successfully is to compare the cost of maintenance of the two above mentioned systems, and if to-day, an electrical system costs less to operate and keep than a horse system, it is simply a question of a short time as to the replacement of the horse by the electrical method. Of course in considering the economy of any system, depreciation enters largely as a factor; but, in case of any new system such as is under consideration, the determination of the

depreciation of any of the various parts or of the system as a whole, would be difficult and for its solution would require long continued service and close observation. Owing to the short time that the automobile has been in the field in commercial competition with the horse, it has been impossible to collect a sufficient amount of data on this point to make its introduction of value in drawing a comparison between the total operative costs of the two systems.

SECTION I.

Some Data on Horse Delivery Service.

The work done by a horse in moving a vehicle over level ground, consists in overcoming resistance to motion due to friction; it may be conveniently expressed in foot-pounds. When grades are encountered, the number of foot-pounds of work performed in the same distance will increase. This additional work is necessary to overcome the force of gravity. When on a descending grade, the horse does work in resisting the tendency of the vehicle to accelerate. Hence, when in motion, the horse is continually doing work. The exact amount of work performed by a horse in a day is a very variable quantity. It depends upon many factors, some of which are:

1. Kinds of road surface—macadam, asphalt, etc.
2. The condition of roads traveled over.
3. Topography of the country passed through.
4. Nature of the load.
5. Distribution of the load on the wheels.
6. The horse itself.

The horse is not an automatic machine that can be designed to perform a given amount of work with a given efficiency. It is, on the contrary, a most variable and, at times, wilful source of motive power. The breed, state of health, temperament, environment, adaptation to the load, etc., affects in a greater or less degree, the amount of work that can be performed in a day by any individual horse. Therefore the problem of determining the amount of work done by a horse, under any but very regular and systematic conditions, is one of great complexity. But under regular conditions, the amount of work performed may be quite closely approximated. It is proposed in this section to give the results obtained in an investigation which was undertaken to determine, as closely as possible, the average

amount of work performed daily by a certain lot of horses engaged in the delivery service of a large dry goods store in New York city.

It may be well to explain in some detail the exact nature of the work required of this class of horses. The large "department stores," as they are now called, have to keep in operation winter and summer, irrespective of the weather, a delivery service which must be as regular in the fulfilment of its functions as the local steam railroads and street railway systems are in the execution of their obligations. The nature of the service necessitates a highly organized system of delivery by means of small units capable of carrying 700 to 800 lbs., over short distances and with considerable speed. This problem has been met and solved by these stores through the introduction of a horse delivery service composed of many small units, each one of which has its special district to cover and a certain time schedule to follow.

To illustrate more clearly the method pursued, we will follow one of these units through its daily routine. Let us consider the case of a wagon making three deliveries a day. The first delivery starts from the stable at 8 o'clock in the morning and arrives at the store a few minutes later—the stable, in most cases being not far from the stores. Arrived at the store, the wagon receives its load, which varies from day to day, but which will average the year round, not over 800 lbs. This load may be taken as the average load on all trips as the wagon leaves the store. The load decreases as deliveries are made, so that theoretically when the wagon has reached the store again, it should be without load. This however, seldom happens in practice, as there are many C. O. D. packages in each delivery that must be returned to the store as collection could not be made. Also packages sent out on approval are called for and brought back to the store on each trip. Hence, as a general thing, the load does not entirely disappear before the wagon reaches the store at the end of any one delivery. It may be safely assumed however, that the average load carried throughout any trip will not be more than 500 lbs. The load having been received, the wagon starts out to deliver its packages.

The following table gives for a certain store, the division of the city into what may be called unit districts, each store having of course, its own particular scheme of subdivision—this depending upon the volume of its business.

TABLE I.

1	Canal St., to Battery,	East and West	2	deliveries a day.
2	" " " 19th St.,	East of Fifth Avenue	3	" "
3	" " " 19th "	West of " "	3	" "
4	20th " " 40th "	" " " "	3	" "
5	41st " " 59th "	" " " "	3	" "
6	60th " " 75th "	" " " "	3	" "
7	76th " " 90th "	" " " "	3	" "
8	91st " " 105th "	" " " "	2	" "
9	106th " " 125th "	" " " "	2	" "
10	126th " " 145th "	" " " "	2	" "
11	20th " " 50th "	East " " "	3	" "
12	51st " " 80th "	" " " "	2	" "
13	81st " " 110th "	" " " "	2	" "
14	111th " " 145th "	" " " "	2	" "
15	All above 145th St.,	East and West	1	" "

It will be observed that on the longer trips only two deliveries are made a day, while above 145th street only one delivery is made. This latter is an all day route and the horse that goes up one day comes back the next—horses being changed at the local stable of this particular store near 180th street.

Let us suppose that the wagon has started on trip No. 7, then it will go from that store to 76th street without stopping, the first delivery being made in 76th street. To make it easier for the horse and to facilitate the delivery, the driver does what is called "backloading." This means giving a number of packages to his helper or delivery boy to distribute on foot, while he drives to another street, makes some deliveries and meets his boy again at some pre-arranged point. By this method the horse is saved a great deal of work and the time of delivery is much shortened. After the deliveries are all made on the way up, for example, between 8th Ave. and Amsterdam Ave. as far as 90th street—the end of this route—then the wagon comes down delivering between Amsterdam avenue and Riverside Drive to 76th street. At this point deliveries stop, and the wagon proceeds to the store, there to deposit the money collected on C. O. D. packages and to return undelivered goods. By this time it is usually after 12 o'clock and the wagon goes to the stable to change horses and prepare for its second trip. The horse used on the morning trip is sent to his stall and a fresh one is harnessed to the wagon. The wagon starts out again at 1 o'clock to load up for another delivery. The same procedure as before is carried out, the wagon usually returning to the stable a few minutes before 5 o'clock. The horse used during the morning trip is harnessed to the wagon again and starts out on the 5 o'clock delivery. This horse returns about 7.30 or 8 o'clock. Hence we

see that it takes two horses for every delivery wagon—the horse that makes only one trip on any one day, making two trips on the following day, on a route calling for three deliveries each day. On a route having two deliveries a day, each horse makes but one trip a day.

It has been found that the mileage per wagon per day is nearly a constant, irrespective of the number of trips made. The method pursued which led up to this conclusion, was the following: An odometer was placed on the axle of a delivery wagon in the service of one of the large department stores in the city. This wagon was sent over each of the routes specified in Table I, an accurate record being kept of the number of miles covered by the wagon on each day. This wagon was kept on the various routes in regular delivery service for a period of some three weeks, and the results obtained indicate that approximately the same number of miles are covered by all the wagons in this service each day. This will be readily understood when one considers that a wagon, making a trip over an apparently short route, is in reality covering very much more ground than would at first be thought. The density of population in the district which the route covers materially affects the number of deliveries and consequently the mileage of the wagon. The explanation of the fact that the average mileage per day of the wagons is nearly the same, is that experience extending over many years of service has taught those in charge the best method of district subdivision which will produce such a proportioning of the work that it shall be equally distributed among the units.

In determining the amount of work done per day by one of these delivery horses, it is essential to know the number of miles traveled by the horse, the average draw-bar pull of the wagon, and the average speed of the horse while in motion. To determine these factors one of the authors spent a number of days on his bicycle, following delivery wagons of many firms, under varying conditions of load and in many different streets. Attached to the bicycle ridden, was an accurately tested cyclometer and an equally accurately tested tachometer. A notebook, pencil and watch completed the outfit, and the following is an illustration of the method pursued in determining the amount of work done by horses attached to delivery wagons in New York city.

The draw-bar pull of the wagon was determined by the use of

a traction dynamometer. For the wagons under consideration it was found that the average pull per ton was 60 lbs. on ordinary cobblestones at a speed of seven miles per hour. On asphalt the draw-bar pull was found to be 40 lbs. per ton at 7 miles per hour. The unit under consideration was composed of a wagon weighing 1300 lbs. drawn by a horse weighing 1100 lbs. Each wagon is provided with a driver and a delivery boy. The average weight of the driver may be taken at 150 lbs. and that of the boy at 125 lbs.. Hence the total weight of the unit without load was 2675 lbs. To this must be added the average load which may be considered as being 500 lbs. Adding this to 2675 lbs. we have as the total weight of the unit 3175 lbs. The weight causing the draw-bar pull however is 2075 lbs. The test recorded below was approximately one-half on cobblestones and one-half on asphalt. The true average draw-bar pull may then be taken as having been 50 lbs. per ton during the test.

The results given in the following table may be considered as showing relatively the average amount of work done by a horse in harness during about 4½ hours in delivery service.

From the above data we find that, starting from the store, the average speed while in motion was 6.7 miles per hour. The actual running time was 1 hour 36 minutes; time at rest 2 hours 28 minutes.

From the time the horse left the stable until he returned to it was 4 hours and 52 minutes. The time taken to load at store was 46 minutes. The time to run from stable to store was 2 minutes. Hence the actual time the horse was working from the time he left the stable until he returned to it was 1 hour and 38 minutes; time at rest 3 hours and 14 minutes.

It will be noticed that the horse was at rest and doing no work for nearly two-thirds of the time.

Taking the draw-bar pull as found, at 50 lbs. per ton, the number of foot pounds of work done by the horse in traveling 11 miles was $50 \times 58{,}080 = 2{,}904{,}000$ foot pounds, or at the rate of 1,781,596 foot pounds per hour, which is at the rate of 29,693 foot pounds per minute. This delivery horse then exerted nearly .9 of a theoretical H. P. for 1 hour and 38 minutes. This was all the work done by this particular horse on this day. The following day this same horse made two trips over the same

TABLE II.

Tabulated Statement of Test.

The weight of wagon	....	1300 lbs.
" " driver	....	150 "
" " boy	....	130 "
" " extra boy	....	120 "
" " average load	....	320 "
Total weight causing draw-bar pull	....	2,050 "
Draw-bar pull	....	50 "

In the following S = started; m = in motion.
R = stopped; r = at rest.

REMARKS.	Speed in miles per hour	At rest and in motion.		Hrs.	Mins.	Secs.	Distance in miles.
		Mins.	r or m.				
Left Stable				1	0	0	0
Arrived at Store	6	2	m	1	2	0	.02
Left Store		46	r	1	48	0	
Stopped at 65th St. to deliver special delivery package	7	23	m	2	11	0	2.67
Started	9	1½	r	2	12	30	
Regular delivery begins here.							
R	9	2½	m	2	15	0	3.045
S		4	r	2	19	0	
R	5.4	2	m	2	21	0	3.32
S		½	r	2	21	30	
R	10.8	½	m	2	22	0	3.32
S		14½	r	2	36	30	
R	4.8	2	m	2	38	30	3.48
S		6½	r	2	45	0	
R	6.42	2	m	2	47	0	3.695
S		4	r	2	51	0	
R	9.6	1	m	2	52	0	3.855
S		4½	r	2	56	30	
R	5.4	1½	m	2	58	30	3.985
S		25	r	3	23	0	
R	6.42	2	m	3	25	0	4.2
S		1	r	3	26	0	
R	5.7	1	m	3	27	0	4.295
S		3	r	3	30	0	
R	6.48	4½	m	3	34	30	4.76
S		15½	r	3	50	0	
R	5.4	3½	m	3	53	30	5.09
S		7½	r	4	01	0	
R	6.6	1	m	4	02	0	5.2
S		1	r	4	03	0	
R	7.5	1	m	4	04	0	5.325
S		4	r	4	08	0	
R	6.24	2	m	4	10	0	5.53
S		1	r	4	11	0	
R	1.2	½	m	4	11	30	5.54
S		½	r	4	12	0	
R	9.6	1	m	4	13	0	5.7
S		8	r	4	21	0	
R	7.2	1	m	4	22	0	5.82
S		6½	r	4	28	30	
R	6.9	2	m	4	30	30	6.05
S		1½	r	4	32	0	
R	4.8	2	m	4	34	0	6.21
S		8	r	4	42	0	
R	7.2	5	m	4	47	0	6.81
S		1	r	4	48	0	
R	6.3	2	m	4	50	0	7.02
S		21	r	5	11	0	
R	7.68	2½	m	5	13	30	7.34
S		1	r	5	14	30	
R	5.4	1½	m	5	16	0	7.46
S		1	r	5	17	0	
R	6	½	m	5	17	30	7.51
S		1	r	5	18	30	
R	10.2	1	m	5	19	30	7.68
S		1	r	5	20	30	
R	7.2	1½	m	5	22	0	7.86
Delivery over, started for stable.		1	r	5	23	0	
Special stop at 28th St. & 7th Av.	7.24	20	m	5	43	0	10.25
		4	r	5	47	0	
Stable	7.5	5	m	5	52	0	10.86

ground. From this data the average work done per day the year round by a horse in this class of service, may be taken to be not over 16.5 miles at 50 lbs. per ton, at a speed of 7 miles per hour. Other data bears out this conclusion. It is quite probable that on some special occasion a horse may be called upon to do more than is shown above, but the average work, day by day, for the year is not more than this. In fact experience has shown that a horse in delivery service in New York city cannot average over fifteen miles a day for six days a week and be expected to render good service for any reasonable length of time.

The length of the working life of a horse in this service, is seldom over five years. At the end of this time he has depreciated in value at least 50% and cannot be sold for more than half his original cost.

The time that a horse is in harness per day the year round, will not average more than seven hours, and we have seen that he is only working a small fraction of this time. However, for the purposes of this paper, it will be considered that a horse can do a greater amount of work, day in and day out the year round, than experience has indicated that he accomplishes.

We will assume, therefore that it is possible for a horse to do 21 miles a day under a draw-bar pull of 50 lbs., at seven miles per hour and be in harness eight hours a working day, the year round.

The number of foot-pounds of work done per day by a horse, under this supposition, would be 5,280,000. This is at the rate of 29,333 foot-pounds per minute, or the horse is working at the rate of .89 of a theoretical H. P. for three hours per day. This of course, refers only to the time in actual motion.

Having established the amount of work that a horse is to do per day, it is now necessary to ascertain how much it costs to do this work. The basis upon which this calculation can most readily be made, for comparison with other values, is the ton-mile; that is, how much it costs to transport a ton one mile over a level road under ordinary conditions; the ton weight to include everything that enters as a factor in causing the draw-bar pull of the wagon. These factors are, the weight of the wagon, weight of driver and boy, and weight of load carried. In order to facilitate the calculation, the data collected has been condensed into a table and is given below. This table represents the results of a personal canvass of a large number of stables for

delivery and for general livery service. The figures given are the lowest that were procurable in New York City.

TABLE III.

TABLE OF ITEMS ENTERING INTO THE CALCULATION OF THE COST OF MOVING A TON A DISTANCE OF A MILE ON LEVEL GROUND, IN LIGHT DELIVERY SERVICE IN NEW YORK CITY.

1.	Cost of food per day for one horse.....	32.00 cts.
2.	Interest on cost of wagon (at 6% per annum) per day, original cost of wagon, $312..........	5.13
3.	Interest on cost of horse (at 6% per annum) per day, original cost of horse, $125......................	2.06
4.	Interest on cost of harness (at 6% per annum) per day, original cost of harness, $55..........	.90
5.	Part of stable rent charged to each horse per day,..... (Cost of stable, $40,000. Int. at 6% = $2400.) 46 horses in stable, part of rent chargeable to horses = $1578.55.	9.39
6.	Part of stable rent chargeable to each wagon per day, 24 wagons in stable... .... Part of rent chargeable to wagons = $822.85.	9.39
7.	Part of cost of attendance chargeable to each horse.... 4 men to take charge of 46 horses at $11 a week per man—$44. a week for care of horses.	13.66
8.	Shoeing per horse per day ($2. per month a head, the year round,)................................	6.60
9.	Driver per wagon per day, $12 per week.............	171.42
10.	Boy helper, $8. per week..........................	114.28
	Total cost of 1 wagon, 1 horse and attendance per day	364.83c.

It is to be understood that this table represents the actual cost per day, to a stable in the city, for a wagon and horse, the figures given being those of a stable connected with one of the large dry-goods houses in the city.

Assuming 500 pounds as the average load carried by any one wagon per day, the total weight of the unit which causes the draw-bar pull as found before, is

Wagon..................	1300 lbs.
Driver	150 "
Boy..	125 "
Load....................................	500 "
Total....................................	...2075 "

Hence, draw-bar pull being taken as 50 lbs., the cost to move 1 ton 21 miles may be taken as 364.83 cents, the cost per ton-mile being then 17.373 cents.

Taking another case where the two horses and the delivery wagon are considered, and assuming the most ideal conditions, we find the following:

TABLE IV.

Supposition:

One wagon making three deliveries a day of 800 lbs. each—assuming 500 lbs. average load as before, making a total delivery per day—2400 lbs.

To do this will require 2 horses, 1 wagon, 1 driver and 1 boy. The cost per day of this outfit from Table III is as follows:

1.	Food for 2 horses	64.00 cts.
2.	Interest on cost of 2 horses	4.12
3.	" " " " wagon	5.13
4.	" " " " 1 set of harness	.90
5.	Stable rent chargeable to 2 horses	18.78
6.	" " " " wagon	9.39
7.	Attendance on 2 horses	27.32
8.	Shoeing for 2 horses	13.20
9.	Driver	171.42
10.	Boy	114.28
	Total	428.54 cts.

The cost of delivery per pound is then .17856 cents. If we assume that in doing this work the wagon was out 12 hours and is in motion one-half its time, going at a speed of 7 miles per hour while in motion, then the wagon will cover 42 miles per day. Under these conditions the cost per ton-mile is 10.2 cents. This is also the cost per car mile in this case.

If we consider the load only, it costs 10.2 cents. per 500 lbs. per mile, or at the rate of .0204 cents per lb. per mile.

If we assume that on the three trips the deliveries average 50 per trip, then 150 deliveries were made per day. This is at the rate of 25 deliveries an hour or 1 delivery in 2.4 minutes. It is well to call attention here to the fact that a wagon is sometimes called upon to make as high as 100 to 150 deliveries on a single trip and the average rate of delivery may be taken as not over 25 deliveries an hour. Hence it is evident that the case considered in Table IV. is for ideal conditions only. The weight per package under our supposition is 16 lbs. and it is not often that the packages will average over 10 lbs.

The results deduced from Table IV. it will be understood, represent the lowest possible figure under the conditions now existing in the stable under consideration. Therefore, if, in making a comparison between the cost of operating a horse and an electric delivery service under identical conditions, the above figures

are used, all possibility of error in favor of the electric automobile would seem to be eliminated.

SECTION II.

Some Tests on Electric Automobiles for Delivery Service.

The results recorded in this section were obtained under service conditions, in the streets of New York city. Over 60 miles were covered during the tests recorded below, and all grades between the lower section of the city and Washington Heights were surmounted with the greatest ease. During the tests, various conditions of weather were encountered, including heavy rain, strong head winds and muddy streets, as well as very clear weather, no wind, and dry streets.

During the series of tests, no accidents of any kind happened. It was not necessary at any time to stop the vehicles for repairs —all the mechanical and electrical parts performing their functions with the utmost ease, and with practically no noise, and absolutely no odor.

The method followed during all the tests was the same. It consisted in measuring the watt-hours of energy supplied by the storage batteries during the runs, by means of a Thomson recording watt-hour meter, which was accurately calibrated before the test began. The distance traveled by the vehicles was recorded by a tested cyclometer, and the speed in miles per hour was noted at any second by means of a tachometer. Placed in series with the watt-hour-meter, was a Weston portable ammeter, while a Weston voltmeter was placed across the battery connections at the controller. In this way, instantaneous readings of the power were obtained, while the watt-hour-meter gave the total energy used. The Weston instruments were accurate, and every precaution was taken to guard them from any jolts or jars which might have impaired their accuracy.

The first tests to be presented were made upon a vehicle built for a large dry-goods store in New York city. The vehicle was intended for the delivery of light goods about the city, and was to be placed in competition with horse delivery service of the same class. The results tabulated below, show the instantaneous power consumption with this vehicle, while traveling over the same ground, at the same speed as recorded on two different days. The column headed "rain" refers to readings taken during a severe storm which lasted throughout the entire test.

The column headed "clear" shows the consumption of power on a clear day with no perceptible wind.

TABLE V.

LOCATION OF VEHICLE AT TIME OF READING.	Speed in miles per hour.	Voltmeter Reading.		Ammeter Reading.	
		Rain.	Clear.	Rain.	Clear.
Going North.					
5th Ave. & 19th St	10	87	86	24	24
5th Ave. & 35th St., 4 per cent. grade	7	84	83	44	42
5th Ave. & 38th St	10	86	85	25	25
Passing Cathedral, 50th St. & 5th Ave	10	86	85	26	27
59th St., passing N. Y. A. C	10	86	85	25	25
59th St., East end of Spanish flats, 3 per cent. grade	8	85	84	35	33
61st St. & Boulevard	10	86	85	21	21
76th St. & Boulevard	10	86	85	24	24
104th St. & Boulevard	9	85	84	30	30
Going South.					
119th St. & Boulevard, N. cor. of Barnard, macadam 4 per cent grade	5	80	81	47	44
106th St. & Boulevard	10	84.5	84	22	20
92nd St. & Boulevard, 3 per cent grade	6	84	82	31	32
82nd St. & Boulevard, down grade	12	85	84	17	16.5
Madison Av. bet. 24th & 2[illegible]th St., No. 3 speed	10	83	82	23	22
No 2 speed	5	43	42	10	21
No 1 speed	2	22	21	19	22
7th Ave., bet 19th & 20th St., cobble stones, No. 2 speed	5	42	42	21.5	22

An inspection of Table V. brings us to the conclusion that the power consumption is not greatly affected by change of pavement, as from cobble stones to asphalt. There is, however, a slightly greater power required on wet macadam than on dry, and more power is required on macadam than on asphalt or cobbles. The grades were measured in every case after the tests were completed. In Table VI is given the data obtained during a test run of a little over 13 miles, in very bad weather. For the greater part of the trip, a heavy wind was blowing.

The time given in the last column of this table has no bearing on the speed. The speed may have been 10 miles an hour while running and yet, owing to "slow-ups," stops, etc., the time occupied in passing from one street to another where the readings of the time were noted, may indicate a speed of only 6 miles an hour. The last column was inserted as a check on the trip—the speed in the second column being given as the speed at the time the readings of the voltmeter and ammeter were taken, the watt-hour-meter, of course, taking care of the intermediate fluctuations.

TABLE VI.

LOCATION OF VEHICLE AT TIME OF READING.	Speed in miles per hour.	Volt-meter Read-ing.	Am-meter Read-ing.	Time.	
				Hrs.	Mins.
Going North.					
20th St. bet. 5th & 6th Ave.	9.5	85	28.5	3	13
20th " " "	9.5	86	27	3	14
5th Ave. & 21st St.	10	87	24	3	16
Down grade	10	91	0	3	18
5th Ave. passing Astoria 2½ per cent. grade	8.5	85	34.5	3	20
34th St. & 5th Ave., 3 per cent. grade	7	85	37.5	3	21
36th St. & 5th Ave., 4 per cent. grade	6.5	84.5	41	3	23
39th St. & 5th Ave.	10	86.5	22		
43rd St. & 5th Ave., down grade	12	87	19	3	25
57th St. & 5th Ave., down grade	13	87	18	3	31
59th St. & 6th Ave.	10	86	25.5	3	32
59th St. & 8th Ave.	11	86.5	21	3	35
Passing 22d Regt. Armory on Boulevard	10	86	23.5	3	40
79th St. & Boulevard, down grade	14	86.5	17		
93rd " " "	15	87	16		
110th St. & Boulevard	10	85.5	25	3	53
119th " " down grade		8[illegible].5	0	3	54
Stopped here 18 minutes.					
Macadam.					
126th St. & Boulevard, going north, 4 per cent. grade	4	81.5	47.5		
127th St. & Boulevard, 4 per cent. grade	4	82	47	4	18
Passing Manhattan College, 134th St. & Boulevard, 4 per cent. grade	4	81	52		
135th St. & Boulevard, 4 per cent. grade	4	81	47.5		
Going South.					
125th St. & Boulevard, 4⅛ per cent. grade	3	80	56	4	25
124th " " " " "	3	80	56	4	26
123rd " " 4 " "	3	80.5	51	4	27
122nd " " " " "	3	80	50	4	28
Asphalt.					
118th St. & Boulevard, 3¾ per cent grade	4.5	81	42		
108th " " down grade	14	85	16	4	34
100th " " "	15	85	13		
96th " " 1 per cent. grade	9	84	26		
94th " " 3 " "	6	83	33	4	37
88th " " down grade	13	85	15.5	4	40
69th " " "	12	84.5	20	4	46
65th " " "	10	84	23		
50th St. & 8th Ave.		88.5	0	4	54
26th St.—going East from 8th Ave.	9.5	83	28	5	04
23rd St., bet. Madison Ave. & Broadway, cobble stones, slightly up grade	9	82	33		
20th St., bet. 5th & 6th Aves.	10	83	21	5	13
At end of run		88	0		

A study of Table VI, shows us that on grades, the speed of the vehicle is very much reduced and that the power required to propel the vehicle at the reduced speed is very large—which is quite natural. The table is instructive in showing the relative proportion of increase of power due to grades. It must be remembered, however, that the comparison is made in this case between level asphalted streets and macadamized hills that were very muddy, and that this condition would cause the variation in power to be greater than in the case of grades of asphalt surface. The average of ten readings taken from Table VI, gives the power consumed on level asphalt as follows:

Volts...85.3
Amperes..23.1

It is to be understood that these ten readings were selected from the table with the idea of eliminating up or down grades. The lowest ammeter reading taken was 20 and the highest 26. Above and below these readings the vehicle was on perceptibly up or down grades. It may be well to note that this wagon was equipped with solid rubber tires; these, as is quite generally recognized, absorb slightly less power than pneumatic tires.

Table VII gives the results obtained during a test in very fine weather. The run was one of 6.25 miles over a continually ascending route.

TABLE VII.

The voltage of the battery on open circuit before the start was 91. This is equivalent to 2.09 volts per cell.

LOCATION OF VEHICLE AT TIME OF READING.	Speed in miles per hour	Voltmeter Reading.	Ammeter Reading.	Time. Hrs	Min.	Sec.
Started from 219 W. 19th St.				3	11	15
19th St. bet. 7th & 6th Aves.	10	86	24			
19th St. bet. 6th & 5th Aves.	10	86	25			
23rd St. & 5th Ave.		90	0			
Stopped 30 seconds here.						
27th St. & 5th Ave.	10	85	25	3	18	30
30th St. & 5th Ave.	10	85	24	3	19	40
32nd St. & 5th Ave.	9	86	32	3	20	20
Passing Astoria stopped 15 seconds.						
36th St. & 5th Ave.	8	84	33	3	23	15
42nd St. & 5th Ave.		90	0			
Stopped 20 seconds here.						
49th St. & 5th Ave.	10	85	28	3	30	30
59th St. opp. Plaza Hotel	10	85	28	3	34	15
60th St. & Boulevard	10	83	25	3	39	10
66th " "	10	85	23			
67th " "	10	85	25			
68th " "	10	85	24	3	41	30
69th " "	10	86	24			
70th " "	10	84	22	3	42	0
72nd " "	10	86	22	3	43	10
75th " "	10	85	25	3	44	10
82nd " "	10	85	22	3	46	10
83rd " "	10		25	3	46	27
86th " "	10	85	25	3	47	27
87th " "	10	85	28	3	47	58
88th " "	10	84.5	28	3	48	20
92nd " "	10	84	28	3	49	55
Down grade		89	0			
99th St. & Boulevard	10	84	28	3	51	55
101st " "		84	28	3	52	38
106th St. stopped to take picture, at rest 5 minutes 10 seconds.						
112th St. & Boulevard	9	83	31			
114th " "	10	84	22	4	6	59
S. end Eng. Bldg. Col. Univ.	10	83	27	4	9	29
120th St. & Boulevard		88.5	0	4	10	15

The watt-hour-meter reading during this test showed a consumption of 1364.22 watt-hours. The wagon alone was weighed on balanced coal-scales and was found to weigh 3750 lbs. On

this trip it carried three passengers and the instruments used. The total weight was found to be as follows:

Weight of wagon	3,750 lbs.
" " passengers	413 "
" " instruments	37 "
Total weight	4,200 "

The distance travelled was 6.25 miles and the time actually in motion was 52.75 minutes.

Therefore;

Average speed in miles per hour was	8.44 miles.
The watt-hours per car mile were	218.28
The watt-hours per ton mile were	103.95

It should be remembered that these results were obtained during a run which was always tending up hill as was noted above. This becomes quite evident when the average of the 27 readings of Table VII is compared with the average of the 10 readings taken from Table VI, representing level asphalt.

Average of the 27 readings of Table VII.

Volts	84.72
Amperes	26.25

Average of the 10 readings taken from Table VI.

Volts	85.3
Amperes	23.1

TABLE VIII.

LOCATION OF VEHICLE AT TIME OF READING.	Speed in miles per hour	Volt-meter Reading.	Am-meter Reading.	Time. Hrs.	Min.	Sec.
Started from 120th St. & Boulevard				4	23	10
Voltage on open circuit		89.5				
Going South.						
118th St. & Boulevard, macadam, 3½ per cent. grade		81	40			
S. end. Eng. Bldg. Col. Univ	10	84	25	4	24	20
77th St. & Boulevard	10	83	23	4	35	15
72nd " "	11	84	20	4	36	30
70th " "	10	82	25	4	37	30
Passing 22nd Regt. Armory	12	84	18	4	38	20
Passing Empire Hotel	10	82	23	4	40	30
59th St. bet. 7th & 8th Aves	10	82	25	4	43	15
Passing Spanish flats, down grade	11	87.7	0			
Passing N. Y. A. C.	9.5	82	25	4	45	0
56th St. & 5th Ave	9.5	81	27	4	47	0
53rd St. & 5th Ave	9.5	81	29			
Stopped 10 seconds here.						
39th St. & 5th Ave		82	22	4	56	30
Ran through 26th St. to make special tests, stopped one minute here.						
5th Ave. & 24th St	9	81	22	5	15	0
19th St. bet. 5th & 6th Ave	9	82	20	5	19	50
End of run		87	0	5	21	45

Table VIII. gives the results of a run made in the opposite direction to that recorded in Table VII., that is starting on the

high ground on which the run of Table VII. terminated; it records the power consumed during a run of 7.24 miles. The run ended where that of Table VII. began. Thus in the run recorded in Table VIII. the tendency was always down hill; this will be appreciated from an inspection of the table.

The watt-hour-meter showed a consumption of energy on this run of 1243.38 watt-hours. The weight was the same as previously given, namely 4,200 lbs. The time in actual motion was 58.5 mins. The distance travelled was 7.24 miles. The average speed per hour 8.08 miles.

The watt hours per car mile were	171.74
The watt-hours per ton mile were	81.08

Combining the results of the watt-meter readings for the tests of Table VII and VIII, we find that for a total distance of 13.49 miles the average was as follows:

Watt-hours per car mile	195.01
Watt-hours per ton mile	92.875

The results were obtained under the ordinary service conditions and can be duplicated at any time.

To determine as accurately as possible the lowest value for the power consumption at the different speeds, some special tests were made. A block paved with asphalt which was fairly level between 24th and 25th streets, on Madison Avenue, was selected for the tests. The method of procedure was as follows: First, readings were taken while the vehicle was passing between 24th and 25th streets and then readings were taken when passing back over the same ground, in every case care being taken that the vehicle had reached a constant speed an appreciable time before the readings were noted. The average of these readings should, of course, eliminate any slight grades, if present, and the average should give the true power consumption for absolutely level asphalt. The readings obtained for the three different speeds of the wagon were:

	Volts.	Amperes.
No. 3 speed—10.5 miles per hour	82	22
	82	20
Average	82	21
No. 2 speed—5.4 miles per hour	42	21
	42	18
Average	42	19.5
No. 1 speed—2 miles per hour	21	22
	21	16
Average	21	19

At No. 3 speed the rate of travel was 15.4 ft. per second and the rate of work 1722 watts. Since a watt represents 0.7373 foot pounds per second, the total work required to propel the vehicle at this speed for one second was 1269.63 foot pounds. This represents a rate of 2.3 H. P. The draw-bar pull was then 52.44 lbs. or at the rate of 39.26 lbs. per ton. At No. 2 speed the draw-bar pull was 36.3 lbs. per ton. The value of the draw-bar pull at No. 3 speed is probably very closely approximate to the value that would be shown at all speeds between 5 and 12 miles per hour if a dynamometer were used. From the results recorded in Table VII. we may take 105 watt-hours per ton mile as quite within the reach of actual practice under service conditions to-day. However, a more conservative estimate of 120-watt-hours per ton mile as a basis upon which to calculate the operating costs of electric vehicles for delivery service will be assumed. Under ordinary conditions a well-designed electric delivery wagon should not consume over 120 watt-hours per ton mile. In support of this statement the following data is presented, these results being obtained while testing a small carriage which, owing to a number of circumstances, had failed to come up to the expectations of the designers. This carriage had been sent back to the shop for some alterations and it was at that time that an opportunity was afforded for making a number of experiments and tests upon it. The point of greatest interest in these tests is the fact that though working under most unfavorable conditions, the watt-hours per ton mile did not reach 120. The weight of this vehicle was 1200 lbs., over 300 lbs. more than the original design called for. With one passenger and the instruments it weighed 1400 lbs. Its draw-bar pull was found, by a dynamometer, to be over 42 lbs. at 8 miles per hour on level asphalt. This is at the rate of 62 lbs. per ton, and is approximately the same as found for ordinary horse delivery wagons on cobble stones. This excessive draw-bar pull was due to poor bearing design. Table IX gives the result of a run of 9.45 miles with this vehicle on New York city streets.

TABLE IX.

Distance traveled	9.45 miles.
Watt-hour meter record	771.15 watt-hours.
Average speed	8.0 miles per hour.
Watt-hours per ton mile	116.5

It is interesting to note that even with this abnormal pull the watt-hours per ton mile were only 116.5.

The test recorded in Table X was a fairly severe one so far as hill climbing and bad roads are concerned. The vehicle on this occasion traveled from 59th street up the Boulevard to 137th street and return, taking en route the long hill from 125th street to 137th street on the Boulevard; on the return the hill from 125th street to 117th street was surmounted. The hill-climbing part of the trip was over a very bad macadam road surface. The hill at 96th street and the Boulevard was surmounted twice during the trip and the carriage covered a distance of 14 miles.

TABLE X.

Distance traveled	14 miles.
Time in actual motion	1 hour 47 minutes.
Average speed	7.8 miles per hour.
Total watt-hours recorded	1162.29
Watt-hours per ton mile	118.57

It is worthy of note that with all the hill climbing, the bad roads and the large friction loss due to bad design, the watt-hours per ton mile reached only 118.57. From the above, 120 watt-hours per ton mile would seem to be a conservative estimate for the power consumption of well-designed electric delivery wagons in New York city under ordinary service conditions.

SECTION III.

Horse versus Electric Delivery Service.—A Comparison.

In considering the advantages and disadvantages of two radically different systems for the performance of the same work, the cost is the deciding factor, if other things are equal. Assuming that all other considerations are equal, it will be shown in this section that the cost of operation, maintenance, etc., of the electric automobile is less than for horses in the light delivery service of New York city, the horse being considered in the most favorable light.

From the results recorded in Section II. we are led to the conclusion that, under highly disadvantageous conditions, the power necessary to propel a vehicle through the streets of New York city from the lower part of the town to points situated on the highest ground, including all grades. that may be encountered, will not average more than 120 watt-hours per ton mile. That this is a high figure for vehicles of good design and equipment is evident from the results obtained while testing the delivery

wagon previously mentioned. The fact that the small carriage never reached 120 watt-hours per ton mile, though working under most unfavorable conditions, should lend weight to this conclusion.

Taking 120 watt-hours per ton mile as a basis from which to compute the power consumed by an electric delivery wagon, we will now compare the results obtained in Section I., Table IV., with the results that would be obtained if an electric wagon were substituted.

From Table IV it was found that the total cost per day for 2 horses, 1 driver and 1 boy, was 428.54c. The wagon was to travel 42 miles a day—being an average of 21 miles per day for each horse. The time in motion was assumed to be 6 hours. An electric wagon with an average speed of 9 miles an hour, could cover this distance in 4.66 hours, thus saving 1.34 hours—the other conditions remaining the same. The cost per day for the electric, assuming cost of power at 5c. per K. W. hour, is given in Table XIII.

TABLE XIII.

1. Cost of power for 42 mile run, at 5c. per K. W. hour........ 71.28c.
   assuming power consumption as 120 watt-hours per ton mile.

Weight of wagon....................	3750 lbs.
" " driver........................	150 "
" " boy...........................	125 "
Average load......................	500 "
Total weight......................	4525 "
	2.263 tons.

Watt-hours per car mile, 271.56

" " ' 42 " " 11,405.00 = 11.405 K. W. hours.

Taking battery efficiency as 80%.
Total power to be paid for = 14.256 K. W. hours.

2. Interest on cost of wagon per day.......................... 37.89
   Cost of wagon, $2,300. at 6% interest.
3. Interest on stable rent for one wagon 9.39
4. Driver...171 42
5. Boy..114.28

Total cost per day for 42 miles, 1 wagon, 1 driver and 1 boy 404.26c.

Therefore, cost per pound of delivery is .16844c., or .01012c. less than the figures for the horse. The cost per car mile is 9.625c. or .575c. less than for the horse. Cost per ton mile is 4.25c., or 5.95c. less than for the horse service. If we consider the load only, it costs 9.625c. per 500 lbs. per mile, or at the rate

of .01923c. per lb. per mile or, .00115c. less per lb. than for the horse service.

Attention is again called to the conditions under which this comparison is made. The horse is supposed to be able to average 21 miles per day, doing this at the rate of seven miles per hour, under a draw-bar pull of 50 lbs. In other words, he is doing work at the rate of .89 of a theoretical H. P. for three hours per day. The automobile, on the other hand, is to do 42 miles a day at the rate of nine miles per hour, and the cost of power is assumed to be 5 cents per K. W. hour. Under these conditions the automobile can do the work of two horses in 1.34 hours less time than they can do it in and with a saving of .01012 cents per lb. of goods delivered or at a saving of 24.288 cents per day on a delivery of 2400 lbs.

Now having shown that it is cheaper to use an electric delivery wagon than the present horse delivery wagon—even when the supposition is made that the horse is doing much more work than he really is—it is proposed to make a comparison between the two systems under conditions which actually exist to-day. It was shown in Section IV. that the delivery horse does not average 18 miles per day during the year. We will assume, however, that the horse does travel this distance per day. Each wagon will go 36 miles a day under this assumption; hence the total mileage of the wagon for the year will 11,268 miles. This assumes that on Sundays the wagon does not go out. Then for 52 days a year, at least, the horses have to be fed without any work in return. This, of course, is a condition not met in electric automobile service.

The cost per day for the two horses, wagon, driver, etc., necessary to accomplish 36 miles a day was found from Table IV., Section I., to be 428.54 cents. The cost of covering 11,268 miles will then be $1,562.20. Here it must be remembered that 365 days have to be taken. The cost per car mile is then 13.86 cents.

When we come to consider the electric automobile for a year, covering 36 miles a day, its advantages are brought out very clearly. Since the vehicle, owing to the nature of its construction, does not consume any energy when not in motion, it follows that, during the periods of rest, while deliveries are being made and the wagon is being loaded, there is no more expense than that incidental to wear and tear. This, of course, is common in amount to all vehicles of the same class and may be considered

the same in each case. That a slight loss does occur when the vehicle is at rest, due to local action, etc , in the batteries, is true, but this loss is considered when the efficiency of the battery is taken at 80%. We may say then, that the factor most important in determining the expense of operating an electric vehicle is the price that must be paid for the power. This is a very variable factor indeed and the price per K. W. hour will determine in all cases the amount of saving that will be possible through the use of electric automobiles.

A stable taking power from a large central station would, if of average size, add a load which, if properly distributed as it easily could be, might become a considerable factor in straightening out the load curve of the station. If several stables were supplied from the same central station, this load would become a great source of economy to the station, and power could be sold to them at a very low figure. Owing to the regular nature of the work imposed upon the wagons in delivery service it could easily be arranged to have the electric vehicles charged at night after the heavy load is off the station. They might also charge early in the morning and at noon or at periods that experience would indicate were the most advantageous for the station, the time of deliveries being adjusted to suit the new conditions. In this way a stable should be able to buy power at from 1 to 2 cents per K. W. hour. As this time has not yet arrived we will install for our purposes a small isolated gas engine plant. A plant of this kind should be able to produce a K. W. hour, at the switchboard for 3 cents. Assume the cost for a K. W. hour, as 3 cents, the power consumed per ton mile as 120 watt-hours and the weight as 3,500 lbs., for the wagon. Taking the average load as 500 lbs., weight of driver as 150 lbs., and that of boy as 125, the total weight is 4275 lbs. The cost for the electric vehicle to cover 11,268 miles is given in Table XIV.

TABLE XIV.

1.	Cost of power for 11,268 miles at 3 cents a K. W. hour, and a consumption of 120 watt-hours per ton mile, total weight = 4,275 lbs., = 2,137 tons, watt-hours per car mile = 256.44, K. W. hours per 11,268 miles = 2889 57, taking efficiency of battery at 80% K. W. hours to be paid for = 3621	$108.35
2.	Interest on cost of wagon at 6% for year. Cost of wagon, $2,300.	138.00
3.	Interest on stable rent for 1 wagon, for year	34.28
4.	Driver	625.68
5.	Boy	416.83
	Total cost per year	$1,323.14

Then the

Cost per car mile	11.74 cents.
" " ton mile	5.49
" of power per mile	.961
" " power per ton mile	.45

Hence the saving considering that the horse drawn wagon does 36 miles a day 6 days a week, is 2.12 cents per car mile in favor of the electric vehicle which means a saving of 76.32 cents per day per wagon.

Owing to the greater speed of the electric vehicle, it takes only 4 hours to travel 36 miles as against 5.14 hours for the horse. This is a saving of 1.14 hours per day, or of 356 hours a year.

The figures given above speak for themselves and would appear to be a most effective argument in favor of adopting the electric automobile for delivery service.

SECTION IV.

CONCLUSION.

In light delivery service in large cities, when a number of units are employed by individual firms, the adoption of the automobile would seem to be merely a question of time. For this kind of service it seems pre-eminently the best solution. It is cheaper to operate than horse service, and the mechanical problems have been so far solved as to make the vehicles commercially successful. Though, as stated before, it is not the intention to discuss depreciation, it may be noted that the comparison of the costs of operation as regards food, cost of power, etc., would show a saving in favor of the electric delivery wagon, in one year, of 15%, which, under more favorable conditions as to the price of power, might easily be increased. Assuming, for the moment, that the depreciation in a year is 20% for the electric system, and, under the same service conditions, is only 10% for horse traction, we still have a saving of 5% in favor of the automobile. The advantages that will arise from the substitution of mechanical propulsion for horse traction on a large scale, are so well known and understood, that any extended consideration of the subject seems unnecessary. Among the many advantages, however, the following would seem to be the most important.

1. The hygienic condition of large cities will be improved, and the cost of street cleaning will be decreased.

2. The wear and tear on pavements and streets will be reduced, and the use of rubber tires will lessen the noise in the crowded streets.

3. The traffic in cities will not be as congested, owing to the saving in space now occupied by the horse. When we consider that there are approximately 200,000 horses used in New York city alone, and that a horse increases the length of a unit by nine feet, it can be readily appreciated how great a saving will be effected. Taking the average width occupied by a horse and shafts as two feet, it is seen that 200,000 horses occupy about 3,600,000 square feet, or 82.6 acres of valuable street room.

4. When the use of automobiles has become more general, the cost of operation will be reduced. This is true, for the reason that with an increased output of wagons, the price will decrease, and with the greater use of power, the cost of it for this purpose will diminish.

5. The danger of accident from runaways will be eliminated.

A paper presented at the 16th General Meeting of the American Institute of Electrical Engineers, Boston, June 28th, 1899. President Kennelly in the Chair.

ELECTRIC AUTOMOBILES.

BY ELMER A. SPERRY.

At the National Electric Light Association meeting a few days since, Mr. Crosby gave expression to a sentiment which has been rapidly taking form for the past twelve months. He said: "To-day we are as near sweeping the horses off the street with the automobile, as we were in 1889, in taking them off the tracks with the electric car."

Why, I ask, was the date '89 chosen? True, it marks a decade in the history of a branch of electrical application which has made the most stupendous strides; in fact, distanced all sober predictions as to achievement. It marks more. To those associated with the early development of electrical traction, it was about these years that the conservative engineer began to breathe easily; through rigorous experience that seemed nigh about interminable, he became convinced that at last, insulation and materials peculiar to the art, startlingly new to, and even held in derision by, the traction engineer, could nevertheless be relied upon to do the rugged work of heavy traction.

By '89, what we might call a "motor mortality" under severe conditions of service had been reached, that meant success. In a space then considered contracted, we had found room for ample area of journal and commutation; ample insulation and dielectric, to withstand the voltage strains. Methods of supporting and imbedding insulation and conductors had been devised, that ensured life not only against heat and overload, against vibration, pounding and concussion, and last, but not least, against misuse and abuse at the hands of the non-expert.

It had been an evolution, gradual though rapid; many had

contributed to its success; it had finally placed on a firm basis, the dream of the engineering world from the time of Watt, down; namely, "the rotary motor." The achievement can hardly be over-estimated. Unnumbered engineers had planned, toiled and passed with the solution of this enchanted problem almost within their grasp. A rotary motor with no oscillating or reciprocating part had at last been developed. It delivered torque, pure and simple—constant and regular, and had a capacity

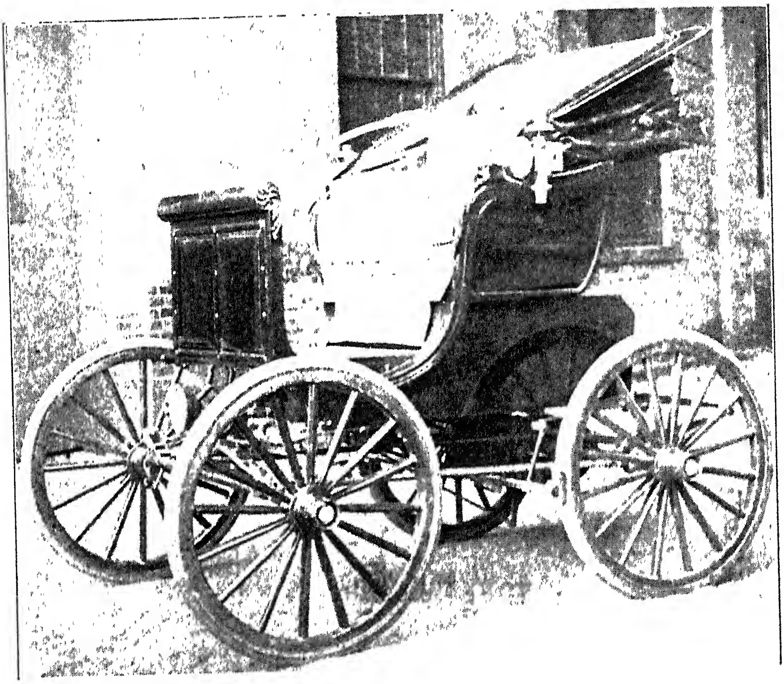


Fig. 1.

measured by its size, and an efficiency measured by other motors, nothing short of wonderful. The motor was simply ideal.

At first, much was said to the effect that the machine was not a prime mover; but it had been "hitched to a star." Its system of connection with the prime source of power was at once so complete, and its association so intimate as to perform more acceptably and economically than the prime mover itself, and as compared with the smaller sources, its economy back to the fuel, even at miles distant, was found to be superior.

The fact that the electric motor is a rotary motor, contributes to the success of electric motor-driven systems to a degree diffi-

cult to over-estimate. Our compressed air friends, compelled as they are, to use a multiplicity of reciprocating engines as motors, have made a long step backward and are certainly in the rear in this, as in other features of their system.

The electric automobile coming upon the scene at this time

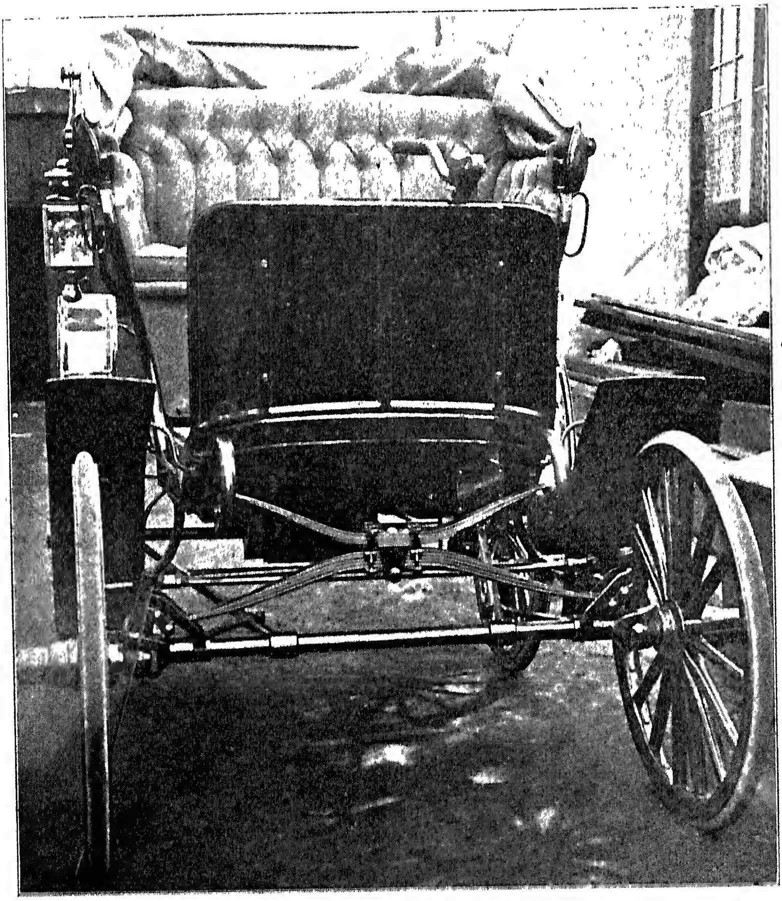


Fig 2.

falls heir to many of the rich results worked out in connection with tramway traction. There are many who go so far as to predict that the younger claimant will displace the former, especially the lighter class of street car service, and this doubtless will be the case to a degree.

Electric railways are rapidly reaching out with wider radii of operation and heavier and heavier equipment, and the automobile

will doubtless have wide use as supplemental to the heavier systems. In fact, co-operation has already been proposed in a number of instances. Its great flexibility and independence of track render it the ideal urban conveyance.

As the perfection of the electric motor gave the first impetus to electric tramway traction, so the point now reached in the perfection of the storage battery will yield equal results in the field of the electric automobile. The past three years have advanced the art remarkably, and drawn to it the attention of both skill and capital, and results have followed.

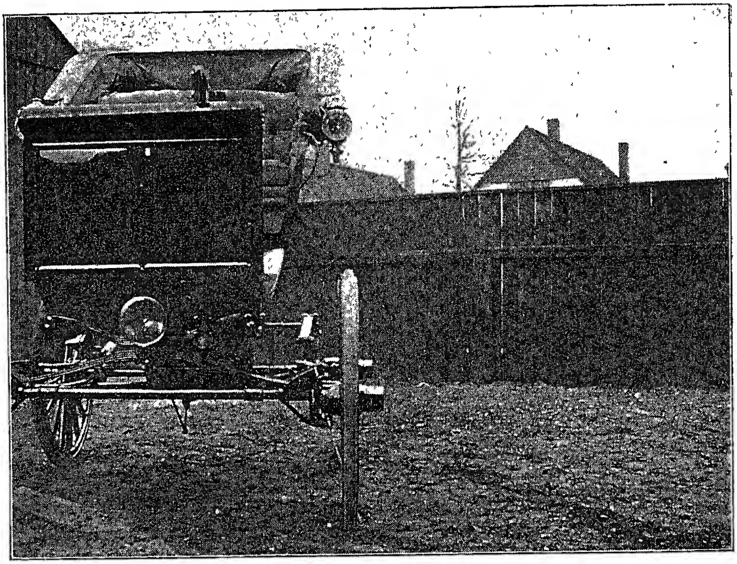


Fig 3.

The perfected storage battery presents some remarkable features. It even rivals the electric motor in its fitness and special adaptability to the automobile problem. Its very large reserve power at instant command ; its entire freedom from danger when fully charged ; its almost constant pressure throughout its capacity; its recently developed capacity for quick charging ; and ease with which charge may be obtained in almost any hamlet in the country, are among its advantages.

The author can state definitely from personal tests of the principal types of batteries built on the Continent and in England that most of the published records are trustworthy as to specific capacity at the various rates. Some of the structures, however,

are open to serious objection from the standpoint of vehicular traffic. For instance, one of the most popular French batteries, though packed with the utmost care, reached this country with 50% of the positives broken off, and upwards of 40 fragments of positive plate disintegrated, per cell. What are we to expect with such a cell in the hands of the non-expert? Fortunately materials are at hand and systems of developing the plates perfected that render them thoroughly reliable and commercial to a degree commensurate with their life. The recent claim of one maker that batteries light enough for traction purposes would live through 5,000 full discharges is hardly credible, though the negatives of some special types seem to indicate a near approach to this figure. The engineer is at present engaged in increasing the

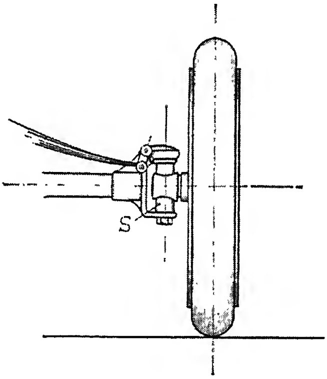


Fig. 4.

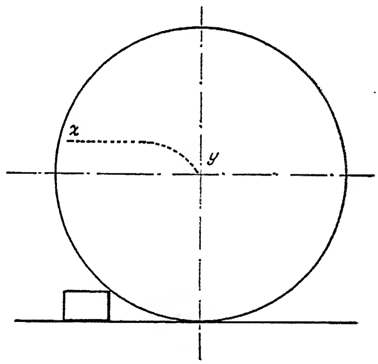


Fig. 5.

life of the light positive, with every indication of success, at least beyond the point ensuring commercial requirement.

It has been supposed that compressed air is the ideal stored power, but it is safe to say that electric storage distances it in the important features. Compressed air reservoirs weigh about 85 pounds per cubic foot capacity for air at 2,000 pounds pressure to the square inch, the air itself weighing nearly 11 pounds. How many horse power hours will this cubic foot develop? Those who know are reticent. It is found that by adding to the air a large quantity of heat, at extra cost, by compounding cylinders and using pressure reducers and wire-drawing valves, all with added weight, that about .27 of a horse power hour may be obtained. We know that this weight of storage battery will develop 1 1-2 horse power hours, requiring no reducing valves

and maintaining its pressure practically at one point until exhausted, rather than gradually exhausting the pressures, as with air. This straight line of discharge of the batteries is not matched by any other storage system of which we now have knowledge.

In common with other systems, the automobile has its limitations which are just beginning to be understood. These are, however, largely those of roadway and materials now employed. The fact that yielding tires are at present (practically) indispens-

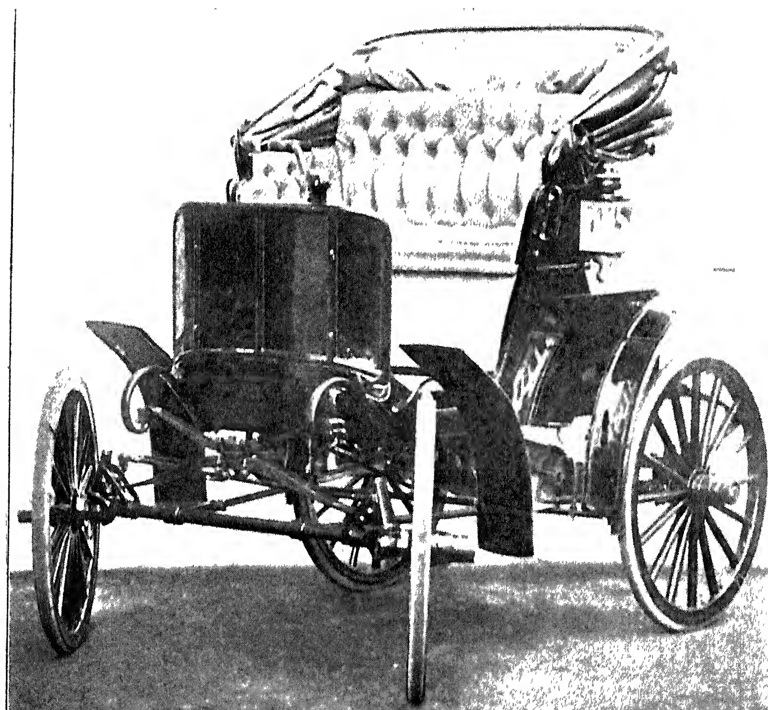


Fig. 6.

able, amounts to a tacit acknowledgment of the prevalent inferiority of roadway and pavements. The universal cry of the automobilist is for good roads, and no one improvement will do more to create a giant industry.

Should the pavements ever be so improved as to render the rubber tire unnecessary, would the steel tire do the work? The bearing of this question upon the heavier class of automobile drays, vans, etc., led the author to cause trials to be made touching this subject. Tests were made with a vehicle, having two

driving wheels, supplied with smooth, wide-faced steel tires, 72″ in diameter, carrying 60% of load. The approximate draw-bar pull was ascertained on various kinds of pavement, dirt and gravel roads and macadam, on the level, and on grades, wet and dry. It was found that under the most adverse circumstances, ample adhesion could be relied upon for any conditions liable to be met. Soapy and greasy Belgian block pavement was found to give most trouble, but even here, 20% drawbar pull could easily be relied upon, with some, but not serious, slipping.

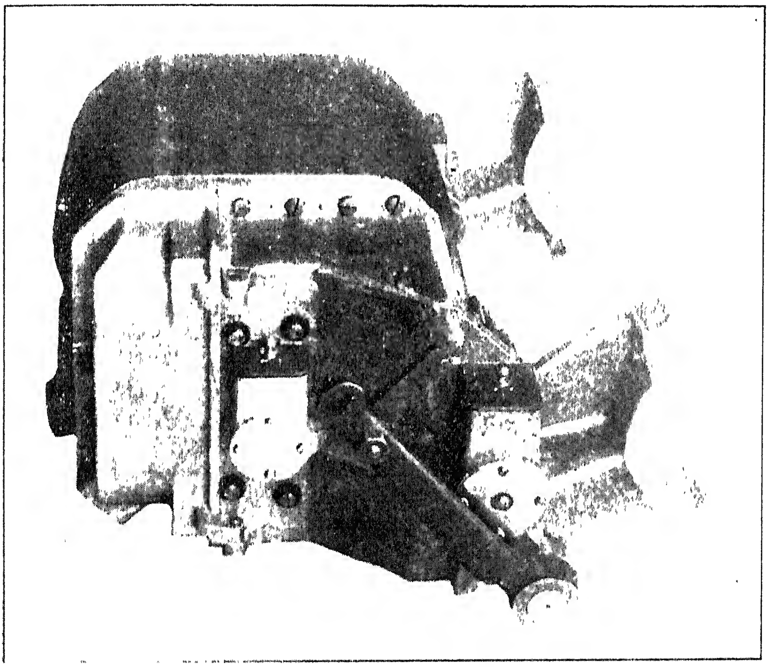


Fig. 7.

A lasting impression of the adhesion and value of smooth tires for road traction, is made by seeing a vehicle of this kind, ascending a 20 per cent. grade on an ordinary gravel road and rising easily, uphill over a 4″ x 4″ timber, placed in front of first one and then both the driving wheels, working as well on the wet portions as on dry.

The designer of the autombile is confronted with some practical problems which have not received attention at the hands of the railway engineer. For instance, in the simple matter of rendering the vehicle directible, and easily controlling the guiding

mechanism. Especially is this true in so arranging the parts that obstructions will not easily derange the mechanism or throw the vehicle out of its course. When one or the other of the guiding wheels encounters an obstruction of importance, the reaction works back to the guiding handle, tending to "whip" it out of the hand of the operator and throw the vehicle out of its course. (Recall the threshing of pole or thills in ordinary vehicles.) Many attempts have been made to reduce the leverage of reaction, but at best it has remained a problem of some importance.

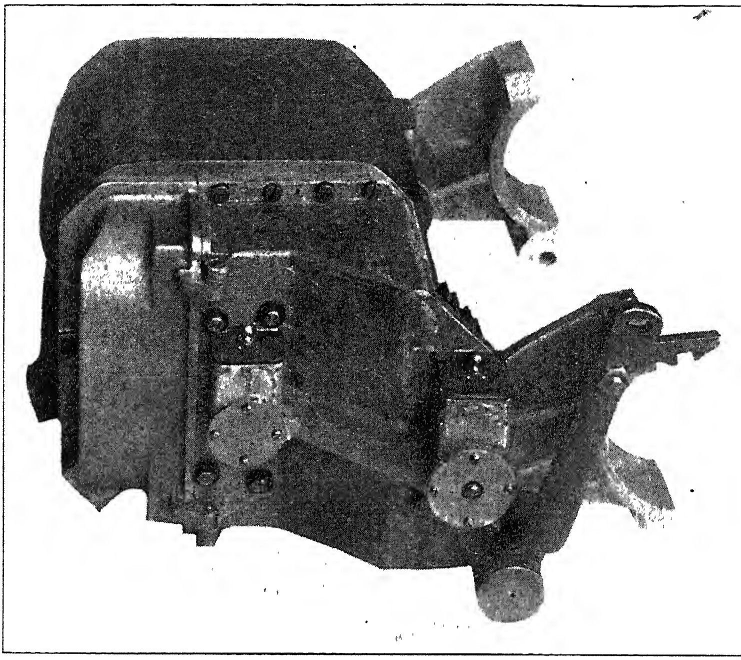


Fig. 8.

The accompanying illustrations, Figs. 1 and 2, shows the method employed by the author. Tests designed to thoroughly demonstrate the practical operation of the device, and especially to compare it with the one ordinarily employed are illustrated in Figs. 3, 4, and 5. It was found that the amount of side-thrust transmitted to the guiding handle was practically in proportion to the leverage measured by the distance between the steering axis and the plane of the wheel, *at the height of the point of interception* of the obstruction. A 20″ controlling handle was connected for equal angular movement with the swiveling axles, the wheels

being the same diameter, viz., 32″ and loaded with the same weight, viz., 370 pounds. A small obstruction causes so flat a trajectory curve as to be negligible; this curve is seen at x y (Fig. 5). I have used, as the height of obstruction, the smallest dimension of an ordinary Belgian paving block, lying upon its side, assuming this to be the standard obstruction to be encountered by the various wheels in these tests. Operat-

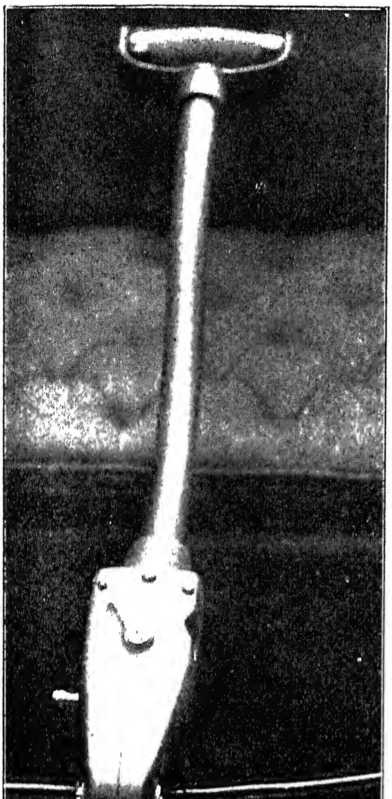


Fig. 9.

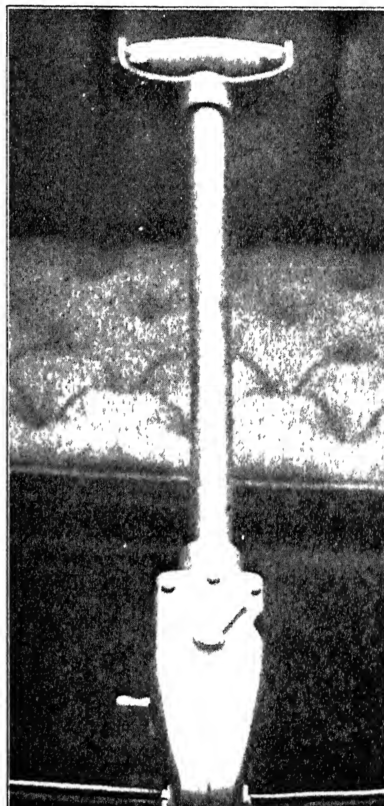


Fig. 10.

ing the two devices each a number of times over this obstruction, at different speeds, a moment of effort upon the handle, tending to swing it laterally, or snatch it out of the grasp of the operator, was found to be in the two cases as follows:
Figure 4, ordinary device; mean value for pull = $10\frac{3}{8}$ lbs.
Figure 2, author's device; mean value for pull = 0 lbs.
This shows an entirely different action under practical operating conditions.

It will be seen from Figs. 2 and 3 that the steering axis is made to intersect the plane of the wheel well up from the bottom or ground line, where obstructions are encountered and where they may be met "head on," and therefore entirely neutralized, as has been demonstrated, giving no tendency to deflection of the wheel in either direction.

It is also found that the arrangement gives the vehicle a quality of self-centering, or running straight-forward, *hands off*.

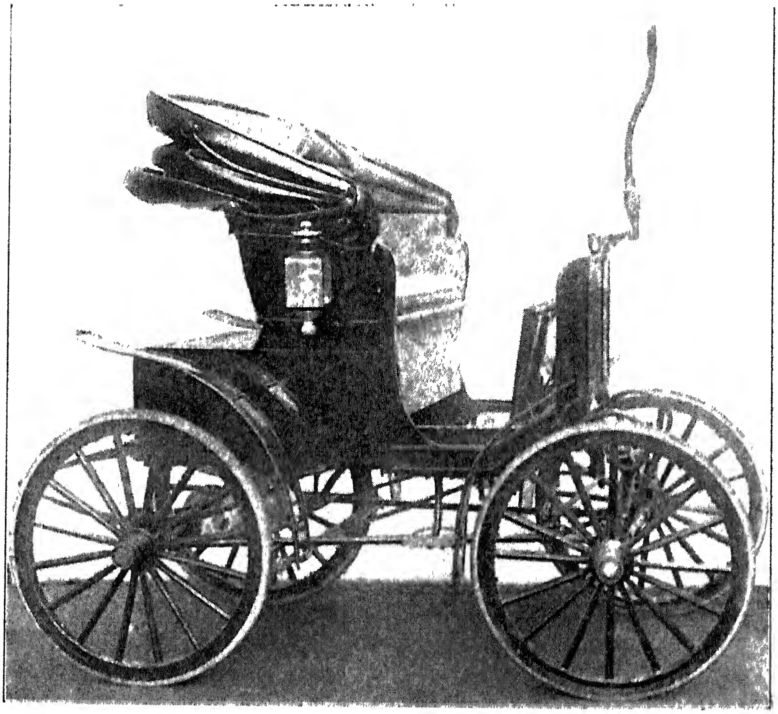


Fig. 11.

This, as will readily be seen, is a natural result of the obliquity of the steering axes. The wheels, when turned, in the act of guiding, describe a conic section, the lowest point of which is the straight-forward running position. Another peculiar feature is, that in this action, each wheel is entirely independent of the other, throwing no stress either upon the connecting or guiding rods. Another excellent effect is the result upon the tires, the act of steering tending to describe a small arc, rather than the usual twisting of the tires. This can be especially noticed when the vehicle is standing still. Fig. 6 shows the inner wheel turned 45°.

This system of mounting the wheels is found to have peculiar advantages on rough roads and over obstructions, preventing entirely the reaction to the steering handle, giving entire immunity from fear of the controlling handle being suddenly wrested from the grasp of the operator; and on ordinary smooth pavements, instantly assuming the forward position, upon being "given the reins." This feature has been employed upon a number of vehicles both here and abroad, and is well received.

It is found with automobiles that while the best practice in

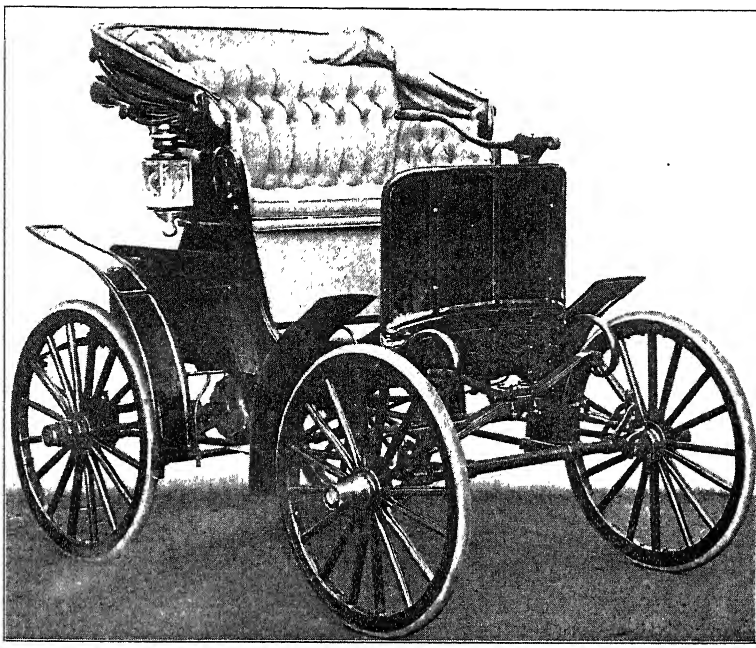


Fig. 12.

tramway traction can be followed closely in the main, yet the different conditions under which the vehicles operate, weight of motor permissible, height at which the motors are mounted, enormous variation in the rolling friction factor, and other points, allow of departures, which have an important bearing on the motor design and construction. For instance:—With the automobile, only a small motor is allowable. This should be light and yet should deliver all the power necessary in case of emergency. It is found practical to use a motor with a somewhat increased ratio of copper to iron, which should have a high overload capac-

ity, but more than all, it is found that the size and weight of the motor can be greatly reduced, if the gears can be practically compounded. This is especially desirable owing to the enormous variation in the rolling friction factor.

Obstructions and grades are encountered, never met on tram-tracks and at the same time may be coupled with soft road, which, owing to the weights necessarily present, would render progress impossible, unless an inordinately large motor were at hand. At such times, often if a few feet only can be compassed the journey can be resumed. It is under these and similar con-

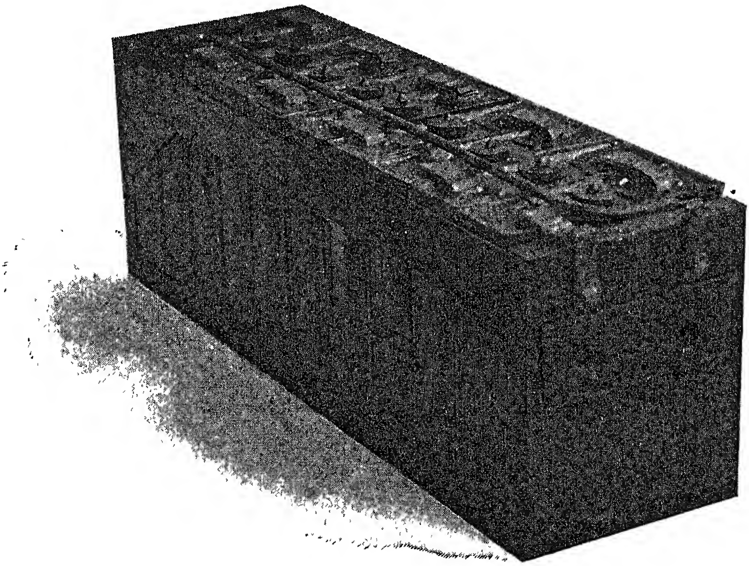


Fig. 13.

ditions, that the value of the compound gear becomes apparent. One form of this gear, employed in a number of vehicles, has been found to be entirely satisfactory, increasing the leverage of the motor over the load. In case of a motor, with a suitable overload factor, this gear, while only doubling the leverage, is found to compass anything that has ever been encountered in city, park and country service. Any ratio of gearing can of course be employed. By means of the compound gear, the torque is brought up to nearly the slipping point of the drivers without overdraft of current-supply from the battery. The manipulation is by a small handle, usually imbedded in the cushion at the side, it being used only at infrequent intervals.

This lever attaches the upright arm seen in Figs. 7 and 8, the gear just being visible. This compound gear not only enables a small motor to meet an emergency, but has an important bearing upon the storage battery, acting as a safe-guard in a very important sense, preventing, as it does, inordinate over-drafts of electric current, and in this way, enabling lighter plates to be employed, without fear of "shedding" the active material. Another feature of importance in connection with the compound gear is found to be its interlock and interaction with the controller. This feature renders the compound gear entirely successful in the most incompetent hands. The gear cannot be thrown or changed, when the current is on, nor can the current be put on until the gear is entirely thrown to either one or the other of its normal operative positions. This is done automatically and without the knowledge of the operator.

Speaking again of the motor, as a whole, its elevated position and the comparatively open space it occupies, when compared with street car motors, enables the employment of ventilation. This should be designed with care, so as to prevent ingress of water and moisture. The ventilation is especially applicable to the small sized motor considering the heavy overloads to which they are frequently subjected.

In the hands of the non-expert, simplicity of control is found to be indispensable to satisfactory operation.

With the automobile, there is one handle, which always should be kept in hand, viz., the steering handle. The question naturally arises, "why not let this handle do all of the work of controlling the vehicle?" In a paper before this body, in 1894, the writer pointed out a system of tram car control, which has since been widely adopted, in which starting, stopping, speed control and brake were confined to the operation of a single handle. This having now been classed as the best practice with tram cars, why not utilize the combination in connection with the steering handle, allowing it, by the most natural and almost trivial movements, to do the whole work of operation. In this way, the entire control of the vehicle is simplified to a single handle. The direction of the vehicle is controlled by lateral movement of the lever, the vehicle going in any direction to which the handle is pointed or aimed. Depressing the handle, from notch to notch, increases the speed, and pulling up the handle, as one would draw in the reins, in case of

emergency, instantly turns off the current and applies powerful brakes. The intensity of the brakes is increased as the handle is further raised. When the speed has been reduced, by again lowering the handle, any of the speed notches can be readily picked up; the speed and brake being always under instant control, *one hand only being engaged.* It is apparent that the current manipulation to the motor and brakes requires only an imperceptible effort. In production, the controlling handle is made either to stay where placed, or is self-raising to the brake position, to suit the fancy of the owner. The controlling handle lying nearly horizontal, the "aiming" action in steering (see Fig. 6) completes the simplicity of the operation.

The controlling head, which is shown in Figs. 9 and 10 is supplied with an indicator showing at all times the position of controlling cylinder. Fig. 9 shows first speed and Fig. 10 the third speed, and by touching a button on the side (seen in Fig. 11) the handle may readily be raised to position shown in the figure, for convenience of occupants, especially for getting in and out on the driver's side.

In crowded thoroughfares, the brake is the most important feature of the automobile. The French authorities in passing upon vehicles, insist upon this factor more than any other, and it is certainly the most indispensable. Whatever else the vehicle can or cannot compass, it must be possible to stop it, and that instantly, on occasions. The brake should be powerful and at least in duplicate. The carriages illustrated herewith are each provided with three separate brake systems.

The location of the controller beneath the foot board (as seen in Fig. 11) is found to present decided advantages in point of convenient interlock and inter-connection with the brakes. The motor cannot be started without first removing all the brakes. This location gives ready access at all times and upon all sides by the hinged floor; gives a natural interlock between the controller and the compound gear above referred to, and also between the controller and charging terminals, which are also here located. Numerous accidents and even wrecks have been caused by failing to open a special motor switch, when placing the controller in series position for charging. A simple interlock, with the charging terminals entirely eliminates this danger, and indeed the interlocking system throughout the carriage very thoroughly protects it in inexperienced hands; for instance, if the directing indicator

(seen in Figs. 2 and 12) is removed, the motor and controller are locked. If the index or pointer of this indicator points forward the vehicle will go forward. If to the rear, the vehicle will go backward. If it points upward, (as seen in Figs. 6, 9 and 11) the carriage may be charged, but when in this position, all the conductors of the motor cable are automatically open-circuited, preventing accident. The pointer can never be manipulated until the controller is first open-circuited, and if the index is only partially turned, through carelessness, or otherwise, the controller cannot be operated until the mistake has been corrected.

The motor being light and small normally, should be of relatively "high speed," still farther reducing the weight. A small motor is possible with the compound gear. The double reduction motor possesses advantages of allowing the hand-brake to be operated on the intermediate shaft, thus working through the compensating gear. A small brake, in this way, gives all the leverage necessary, being one reduction back through steel gears with small peripheral velocity, thus acting without noise. Another advantage of double reduction is in keeping all the gears of the power system small, and thus ensuring a neater appearance. The somewhat higher speed permissible in the double reduction arrangement also renders possible the bipolar motor, with its higher efficiency, as compared with the multipolar. Every condition tending to higher efficiences should be considered in connection with automobile equipment, as conserving the resources of the battery. These conditions are not as necessary with systems of tram traction, where the prime source of power is always available.

The location of the controller and current-manipulating switches low, (as seen in Fig. 11) and in front of the batteries, avoids hydrogen detonation and eliminates all danger of explosion from spark or opening circuit.

Much has been said of one motor versus two. This is largely a matter of mechanics; it is conceded that one motor gives higher efficiency than two of half the power, and is less expensive to maintain. As even the heaviest strains are comparatively small, the compensating gear, where one motor is employed, is easily maintained, yielding a combination which is far simpler and employs less parts than with a double motor equipment.

The automobile will, for some time, necessarily be in the hands of the inexperienced and non-expert, and while it is not

possible to render it "fool proof," yet certain safeguards may be employed in and about its operating devices and charging system, which will materially reduce and almost prevent derangement. The manipulation may be be so thoroughly interlocked as to effectually prevent a wrong operation preceding the right one, and rendering it nearly impossible to make a mistake in anything like normal operation. Interlocks and safety devices are used in many branches of engineering; the introduction of automatic interlocking switches is a notable example, having placed steam railway operation on an entirely new basis. After subjecting these devices to continued practical test, and altering them until the requirements seem to have been met, the author is prepared to say that there is no reason why the important results reached in the interlocking switch and signal system, should not be compassed in automobile manipulation, and by devices vastly simpler and less expensive.

As to charging and care of batteries, it is believed that the differential watt-meter system for ordinary use, coupled with the periodic inspection by an expert from the home office or local headquarters, is the best arrangement now at our command. The author has found that the differential factor of the watt-meter should be adjustable, and should be brought from time to time into step with both the efficiency and charging curves of the battery. These curves change and are peculiarly altered by the time factors. These adjustments are easily made through determinations by the use of hydrometer. This can easily be one of the duties of the periodic inspection above referred to. The practical employment of the adjusting feature, or in fact, any device, by means of which the meter may be kept in step with the battery, is found to constitute such a meter an almost perfect safeguard against the destructive effects of overcharge and overdischarge in inexperienced hands. One tray of the batteries is shown in Fig. 13.

With the public conveyance, or a delivery system, operating a number of vehicles from one station, it may not be difficult to secure the services of a single expert attendant, yet for anything like commercial operation, the automobile itself must be entirely successful in the hands of the "raw recruit." Emphasis should by laid on the fact that the driver must be a man familiar, especially at first, with the routes and business in hand. The vehicle must be depended upon to perform successfully, even

under the most trying conditions, without demanding especial thought or attention on the part of its operator, who should simply be a good driver, and who, from an engineering standpoint, would be considered thoroughly non-expert.

Discussion.

Mr. Hermann Lemp Jr.:—The work of Mr. Sperry is well known. Yet it is well to know, that from personal information I have from Paris, his carriage was rated as A No. 1, and that in the land of the automobile.

Nor will it detract from his work if I say that of all automobile carriages to be built the electric carriage is the easiest. There is only one trouble: The storage battery. Our storage battery friends will say no, the trouble is everywhere else. In other carriages there may be a number of troubles but in the electric carriage there is only one; the storage battery.

Mr. Sperry has laid particular stress upon the value of a safe steering arrangement. I fully agree with him on that. The wheels of an automobile ought to be always locked completely and guarded against any strain from the road, and yet be practically free to be moved by the operator without any particular energy or skill on his part. We have operated a number of carriages by a hydraulic steering check, which need not be described at present.

I am rather surprised that Mr. Sperry should bring up the question of a change of gear. No doubt he has very good reasons for it, but I think he himself this morning made the plea for simplicity in apparatus, and if there is anything that recommends an electrical carriage or a steam carriage, it is that there is only one thing to operate and not two or three. While Mr. Sperry operates all by one lever, I do not think it is real simplicity because it means introducing a number of devices which are apt to give trouble. The electrical carriage in my opinion is paramount in success for its simplicity, consisting only of a battery, a motor, a controller and a brake.

Mr. Sperry seems to be in favor of one motor. I think that is a subject open for discussion. It is said a differential gives no trouble but I think it does. If one of the wheels slips it will at once cause the other wheel to lose traction as well, whereas if the two wheels may be independently moved, one may slip while the other will do the work of two. For that reason, when a single motor is used I would prefer a clutch arrangement. I don't think I have anything more to add on the subject but may communicate a few more remarks later on.

Mr. C. W. Rice:—At page 494 Mr. Sever says the weight of the wagon complete is about one ton, so that the cost to run it is 15 cents per ton mile. Page 503, the weight two tons, and on page 506 he states it cost about five cents, that is two and

one half cents a ton a mile. So that makes a comparative cost between seven and eight times cheaper to operate the electric delivery wagon a mile, than the horse and wagon. The cost of charging in New York city for 14 kilowatt hours will be roughly forty cents. An electric wagon can run about 20 miles which checks up with these figures, making two cents per mile. There are about ten stations where electric wagons can be charged, so that the opportunity for the development of the electric automobile seems to be considerable.

Mr. Sperry:—The compound gear I think I endeavored to point out in the paper was introduced more as a safeguard to our weakest member, the battery; I want to say also about the valuable paper by Professor Sever, to which we have listened that I look upon it as setting up a mile stone marking progress. It shows where we are at the present time. We hope to gain still greater heights and I can assure you that there is work ahead for us all in that line. It is no easy problem, entertaining as it may appear; it is fraught with many practical difficulties, some of which Mr. Lemp has met, and it is worthy of our best mettle, and only by concerted efforts and the best engineering ability obtainable can we expect to equal the time-honored, and most honorable horse. His system of traction is unique, and nature has certainly provided him with a means of locomotion which in "draw-bar pull" is ideal. Again, we have had him so many years, I might say so many thousands of years, that he has become a part of our existence and civilization, and we must not hope to wholly displace the horse. But the demand of the municipalities and cleanliness of our streets, make it necessary that some better motor should be provided. It seems as Mr. Lemp has pointed out, the simplicity of the electric motor is its charm. There are fields for other motors, but we as electrical engineers are interested especially in the electric motor, and as I say we must work together shoulder to shoulder to gain one point after another, and I hope that when another year rolls around we may have indications that substantial progress will have been gained in this matter of displacing the horse in our streets.

Mr. Blood:—In connection with the differential gear, I might state when you come to balance off weight for weight of motor with a double gear or a motor geared direct, you will find not very much saved. Take for instance three sizes of the motor which are necessary for all styles of carriage service, one of two horse power, one three and one five, the first one will weigh about 160 pounds with an armature speed of about 900 revolutions, the second 205 pounds and the third one 250 pounds. With an increase of about 50 per cent. you more than double the torque, double the output, and in order to double the output with differential gear, I do not think they will use more than 2 to 1 gear, the extra weight of the gear and the clutch mechanism and the

handle will come pretty near to 50 per cent. It amounts to somewhat the same thing in case of two motors versus one motor, although the arrangement there I think as Mr. Lemp says is due more to simplicity and ease in running, than to the weight. Although the differential clutch itself does not weigh anything like the increase in the weight of the two motors versus one; the arrangement necessary of the differential clutch entails other points in weight beside itself.

Prof. Thomson:—The question seems to me to involve a sort of balancing between what you like to do and what you must do. The ideal arrangement seems to me to have traction on the four wheels, that is to give each of the forward wheels also a motor, as we can lighten the wheels, lighten the structure, and take off weight here and there from the rear wheels. When we put motors on the forward wheels I am not so sure but that it would come to pretty nearly the same weight in the end, and when we consider that some of the wear and tear of the battery might possibly be saved by this arrangement, it becomes a proposition which we should consider. Of course, I realize the fact that the smaller the motor, the less the efficiency, but there are so many other factors that come in which it is difficult to estimate and balance, that it is worth while to consider all sides of the subject. At the same time it is probably possible to standardize the motors, and that of course conduces to low cost of manufacture. If I ever get an electric vehicle for my own use it will have traction on the four wheels. There is another reason why I say this and that is; in winter time when roads are slippery you want all the traction you can get, four wheels being none too many wheels to do the pulling, especially if you are on a hill rather icy, or if you are climbing over a snow bank. In such cases it does not seem very easy for the rear wheels to push the forward wheels, but if the forward wheels have traction as well as the rear there is a better chance to get over obstructions.

Mr. Sperry:—I would like to say one word about the interesting feature of encountering snow. Last year when we had the enormous snow storms in New York, a representive followed these vehicles and the records they made were astonishing under the circumstances. A vehicle was also running in Cleveland all winter long, so as to get the effects there, and as a result of these two observations I might say that the motor vehicle is not stopped by snow. As Professor Thomson has stated, there could be no harm in constituting every wheel a driver. It is that kind of suggestion we want. And the best efforts of us all are none too good.

The Committee on Resolutions submitted the following report which was unanimously adopted:

Whereas, the AMERICAN INSTITUTE OF ELECTRICAL ENGINEERS at this, its 16th General Meeting, and its 135th consecutive meeting, held in the city of Boston, Massachusetts, June 26th, 27th and 28th, 1899, has been the recipient of many courtesies and privileges during its stay in Boston, which have greatly contributed to the interest, pleasure and profit of the members; Be it resolved;

First, that a vote of thanks be extended to His Honor, Josiah Quincy, the Mayor of Boston for the honor bestowed by his attendance at the opening ceremonies of the INSTITUTE and the felicitous expressions and appreciation of the work of the INSTITUTE as conveyed in his opening address, and for his courtesy in furnishing the steamer, *J. Putnam Bradlee*, in connection with the trip of the INSTITUTE to Pemberton, Nantasket and Braintree.

That a vote of thanks be extended to the Massachusetts Institute of Technology and the various professors thereof for the use of the Walker Building in which to hold the sessions of the INSTITUTE and for the various courtesies received during these meetings.

That a vote of thanks be extended to President Charles W. Eliot, Professor Ira B. Hollis, Professor John T. Trowbridge of Harvard University, and the members of the committee, Professor C. A. Adams, Jr., of the Lawrence Scientific School, W. F. Burke, S. E. Whiting, Professors Sabine and Hall of Harvard, Professor George F. Sever, of Columbia University, Dr. Hammond V. Hayes, Charles F. Hopewell, City Electrician, and others who rendered so enjoyable the visit of the INSTITUTE to Harvard University and Cambridge.

That a vote of thanks be extended to James T. Monroe, President, and members of the Technology Club for the invitation to our members to avail themselves of the privileges of the club during our stay in Boston.

That a vote of thanks be extended to W. A. Bancroft, President of the Boston Elevated R. R. for the use of the trolley cars placed at the disposal of the INSTITUTE in connection with its visits to the Terminal Station, the Boston Electric Light Station, Cambridge, the works of the New England Gas and Coke Co., Norumbega Park, to steamer landing, etc., also for the invitation extended to visit the Albany St., Harvard, Boylston and other power stations.

That a vote of thanks be extended to the Edison Electric Illuminating Co. for the invitation to inspect its five stations for supplying light and power.

That a vote of thanks be extended to the Boston Electric Light Co for the invitation to inspect their various stations for supplying light and power.

That a vote of thanks be extended to the officials of the Boston Terminal Company for the invitation extended to inspect the many engineering features at the Terminal Station.

That a vote of thanks be extended to the New England Gas and Coke Co. and to Messrs G. H. Finn, General Manager; Louis J. Hirt, Chief Engineer and Dr. Schnievrina, chemist, for the courtesies in connection with the visit of the INSTITUTE to the works of that company.

That a vote of thanks be extended to the New England Electric Vehicle Transportation Co. and to Col. Albert A. Pope, for the use of the automobiles placed at the disposal of the INSTITUTE in connection with the visit to Harvard University.

That a vote of thanks be extended to Mr. E. W. Rice, Jr., Vice-President and the General Electric Company, for the cordial invitation to visit the works of the company at Lynn, Mass., and Schenectady, New York.

That a vote of thanks be extended to Professor Elihu Thomson for his invitation for the INSTITUTE to visit informally his home at Swampscott, Mass.

That a vote of thanks be extended to the American Telephone and Telegraph Co. for the courtesy extended to the INSTITUTE in offering the free use of its long-distance telephone lines.

That a vote of thanks be extended to the New England Telephone and Telegraph Co. for placing at the INSTITUTE headquarters a telephone desk and set for free use of our members for Boston and suburban service, together with an invitation to visit their exchanges.

That a vote of thanks be extended to Edgar R. Champlin, Mayor of Cambridge, for the courteous invitation to visit the Manual Training School, pumping station and water works of the city of Cambridge.

That a vote of thanks be extended to Mr. C. Atherton Hicks, President, for the courteous invitation to visit the opening ceremonies of the Needham and Boston Street Railway Company, Wednesday afternoon, June 28th.

That a vote of thanks be extended to Col. Heft and the officers of the N. Y., N. H. and H. R. R., for the use of a special train over the Nantasket branch of their road, and the invitation to inspect the details of both the overhead and third rail supply systems, power houses, etc.

That a vote of thanks be extended to the Boston Local Committee, Professor W. L. Püffer, Chairman; James I. Ayer, Vice-Chairman, and Messrs. Geo. W. Blodgett, Wm. Brophy, C. L. Edgar, W. C. Fish, A. V. Garratt, H. V. Hayes, Chas. F. Hopewell, Sidney Hosmer and Everett Morss for their most able and untiring efforts to make the stay of our members both pleasant and profitable.

WILLIAM J. HAMMER,
H. WARD LEONARD,
W. D. WEAVER,
Committee.

THE PRESIDENT:—In adjourning this meeting I want to say that I think we have had a very successful meeting. We have had very valuable papers and discussions, and I can only hope that when the INSTITUTE next comes to Boston it will maintain the record here established. We have every reason to congratulate ourselves and to thank everybody for entertaining us.

On motion the meeting then adjourned *sine die.*

Associate Members Elected at Executive Committee Meeting, August 23rd, 1899.

Name	Address	Endorsed by
BURKETT, CHAS. WATSON	Assistant, Engineering Dept. Southern Bell Tel. & Tel. Co , 87 South Pryor St , Atlanta, Ga.	J. P. Jackson. J. A. Wotten. F. A Pickernell.
CLARK, WM. EDWIN	With Clark and Mills, Engineers & Contractors, residence, 1440 Mass. Ave., Cambridge, Mass.	Jas. I. Ayer. C. A. Adams. Ralph W. Pope.
DUBOIS, TUTHILL	Electrical Mechanic. N. Y. Navy Yard, 2205 Pitkins Ave., Brooklyn, N. Y.	M. Osterberg. E. R. Knowles. Jas. Hamblet.
GOODMAN, WM. GEO. TOOP	Electrical Engineer, Tramway Construction under N. S. W. Government, Public Works Dep. residence, 86 Bondi Road, Sydney, N. S. W.	G. J. Fischer. J. S. Fitzmaurice. S. W. Childs.
HALL, FRED'K A.	In Draughting Room, Westinghouse E. & M. Co., residence, 6033 Stanton Ave., Pittsburg, Pa.	H. Lemp. Thorburn Reid. John B. Blood.
HALLBERG, J. HENRY	Electrician & Designer of Arc Lamps with Standard Thermometer & Electric Co., Peabody, Mass., residence 151 Lafayette St., Salem, Mass.	T. C. Martin. C. C. Chesney. Jos. Wetzler.
HEFT, N. H.	Chief of Electrical Dept. N.Y. N. H. & H. R. R., New Haven, residence Bridgeport, Conn.	E. C. Boynton. E. E. Higgins. R. W. Pope.
HEWLETT, ERNEST HOLCOMBE	Electrical Engineer in Chief Control Rockhampton Gas & Coke Co., Ltd., residence Estoril Rockhampton, Queensland, Australia.	Arthur W. Jones. G. J. Fischer. Ralph W. Pope.
LANSINGH. VAN RENSSELAER	Electrical Engineer, Western Electric Co., residence 5109 Kimbark Ave., Chicago, Ill.	A. H. Ford. H. H. Wait, Gerard Swope.
MCLAIN, RALPH CLAPP	Assistant Engineer to Constructing Engineer, Naughton & Co., residence 126 East 23rd St., New York.	R. H. Mansfield. F. J. Sprague. A. W. Berresford.
NAPHTALY, SAM. L.	Manager and General Superintendant The Central Light & Power Co. Room 500, Parrott Building, San Francisco, Cala.	N. S. Keith. F. G. Cartwright. A. E. Brooke Ridley
RYERSON, WM. NEWTON	Switchboard Attendant, Metropolitan Street Railway Co., residence 332 West 56th St., New York.	C. O. Mailloux. E. N. Carichoff. G. H. Hill.
STEWART JOHN BRUCE	Superintendent. Electric Plant Virginia Hot Springs Co., Hot Springs, Va.	L. G. Lilley. C. Stowe Reno. Bert L. Baldwin.
WALLER, CHAS. WAITE	Sales Agent, General Electric Co., Boston, Mass.	Sidney B. Paine. Chas. B. Burleigh. Edwin W. Hammer.
WILSON, H. S.	Superintendent, Puebla Electric Light Co., Puebla, Mexico.	J. B. Cahoon. J. R. Lovejoy. R. W. Pope.

AMERICAN INSTITUTE OF ELECTRICAL ENGINEERS.

NEW YORK, September 27th, 1899.

The 136th meeting was held this date at 12 West 31st street, and was called to order by President Kennelly at 8.15 P. M.

THE PRESIDENT:—The Secretary will read the announcements for the evening.

THE SECRETARY:—At the meeting of the Council held this afternoon the following foreign members were elected:

Name	Address	Endorsed by
CAMPBELL, HENRY ARTHUR	Electrician. Jamaica Electric Light & Power Co., Ltd., 38 Harbor St., Kingston, Jamaica.	H. C. Wilson. R. W. Pope. T. C. Martin.
DAVIS, LESLIE FOSTER	Secretary and Manager, Jamaica Electric Light & Power Co.. Ltd., 38 Harbor St., Kingston, Jamaica.	H. C. Wilson. R. W. Pope. T. C. Martin.

Total 2.

The following associate members were transferred to membership:

WILLIAM ENOCH MOORE,	General Superintendent and Electrician, The Augusta Railway and Electric Co., Augusta, Ga.
HENRY M. HOBART,	Engineer, care British Thomson Houston Co., London, England.
G. SACCO ALBANESE,	Electrical Engineer, Tramways Electrique de Nice, Nice, France.

At the same meeting the Secretary was instructed to have printed an edition of one thousand copies of the Standardization Committee's Report. It appeared in its perfected form in the June and July number of the TRANSACTIONS which has been circulated. I make this announcement in order that members who require separate copies in their work may procure them at the nominal price. That is, the retail price has been fixed at ten cents and five cents in quantities of ten or more. The pamphlet as it now appears has been revised thoroughly by this committee and was finally adopted by the meeting at Boston. It appeared as a preliminary report, as you may remember, over a year ago and was discussed at Omaha.

THE PRESIDENT:—The paper for this evening is upon "Series Arc Lighting from Constant Current Transformers" by Prof. Robb who is present and we shall be pleased to hear from him.

A paper presented at the 136th Meeting of the American Institute of Electrical Engineers, New York, September 27th, 1899. President Kennelly in the Chair.

SERIES ARC LIGHTING FROM CONSTANT CURRENT TRANSFORMERS.

BY WM. LISPENARD ROBB.

In all long-distance transmissions of electricity, and when large areas are supplied from a single advantageously located power plant we must, at least in the present state of the art, generate and transmit alternating current.

In general it will be found desirable in my opinion to supply current to the street lights from the same secondary mains that supply the current for the commercial lighting and power. There are, however, in most places large districts in which the streets are lighted by arc lamps, and where there is no commercial lighting or power. These sections can be most economically lighted by series arc lights.

Various methods of operating series arc lamps from alternating current systems have been suggested, and are in successful operation.

In several well-known stations in this country, continuous current series arc dynamos are driven by synchronous or induction alternating current motors, the arc dynamos being either direct-connected to motors or belted from a line shaft which is driven by motors. In England, direct-current series arc lamps are operated successfully from rectifiers. In 1896 the Hartford Electric Light Company, with which I am associated, decided that it would be advantageous to make a radical change in its system of series arc lighting, with a view to obtaing a greater economy of operation. The series commercial arc lamps and the street lamps in the same section of the city were changed over from series open-air arc to constant potential arcs. It was considered advisable to continue the series arc lamps for lighting

the outlying portions of the city. Propositions were considered both for using motor-driven series arc dynamos and for using rectifiers.

An order was finally placed with a manufacturer for a rectifier. A satisfactory rectifier never materialized, and we were unsuccessful in our attempts to import one from Europe.

The development of the enclosed arc lamp quickly led to the evolution of a satisfactory alternating current arc lamp of the constant potential variety. The perfection of this lamp led Mr. Richard Fleming, one of the engineers of the manufacturing company, to suggest the advisability of operating series alternating arc lamps from the constant-current transformer, which formed one of the essential parts of the rectifier.

An experimental transformer having a capacity for operating 30 lights in series, was installed in April, 1898. After being subjected to a thorough test in the central station it was put in practical operation on a street circuit. The results of these tests were so satisfactory that an order was soon placed for several transformers each having a 100-light capacity. The first of these transformers was installed about a year ago and during the year all of the continuous-current series arc dynamos have been replaced by constant-current transformers.

It has seemed to me that it would be of value to some of the members of the INSTITUTE if the data obtained in the operation of these transformers was made a matter of record in the proceedings.

THE CONSTANT CURRENT TRANSFORMER.

Each transformer is enclosed in a cylindrical tank. The tanks were originally made of boiler iron riveted up, but it proved impossible to keep these tight against the transil oil in which the transformer is immersed. The tanks are now made of cast iron.

The core of the transformer is of the sheet type, with a large central vertical core rising the whole height of the tank. This central core is surrounded by the primary and secondary coils and the magnetic circuit is closed by return paths outside the coils. In the transformers as made by the General Electric Company there are two primary and two secondary coils. One of the primaries is fixed at the bottom, and the other at the top of the central core. The two secondaries are free

to move up and down between the primary coils, and are so connected together that when one falls the other rises. They may approach into contact with each other at the middle of the tank, or from this position one may rise toward the primary coil at the top, while the other falls toward the primary coil at the bottom. Connected with the chains by which they are balanced is a lever which extends outwardly from the top of the oil tank and carries depending from its outer end a heavy adjustable weight. The lever is supported on a hardened steel knife-edge. This weight tends to force the two secondary coils respectively toward the two primary coils. When the transformer is in operation the currents induced in the secondary react upon those in the primary and tend to force the coils apart. This force is balanced for the desired normal current by the adjustable weight outside of the case. If the resistance of the secondary circuit falls,

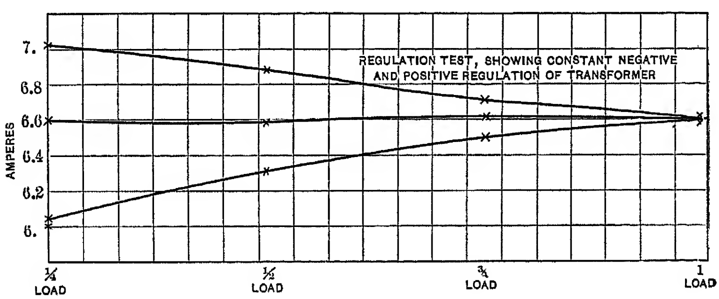


Fig. 1.

due to the cutting out of lamps, the current increases slightly, increasing the repulsion effect, and the secondary is pushed further away from the primary, giving a chance for increased magnetic leakage between the primary and the secondary, which reduces the E.M.F. in the secondary, bringing the current down to practically normal, even with wide changes of resistance. The regulation obtained is adjustable by means of a cam-shaped segment which can be moved on the outer end of the weighted lever.

The principle of regulation was first suggested by Prof. Elihu Thomson and its application to the operation of constant current transformers is broadly patented by him.

By bringing out the proper connections from the secondaries, the total number of lights may be operated as a single circuit, or operated in any desired number of multi-circuits in a manner similar to the well-known method employed on the Brush series dynamos of large capacity.

The larger sizes of this type of constant current transformers are always so arranged that the lights can be run on two circuits, or a single circuit, as may be desired. Owing to the high voltage of the enclosed arc lamp, the 100-light transformers usually operate two circuits connected upon the multi-circuit principle.

The transformer can be adjusted so as to give practically a constant current between one-third load and full load. As the properties of the transformer make it undesirable to run the transformer at less than one-third load, no attempt has been made to so construct the transformer that it would regulate under smaller loads. By adjusting the cam-shaped segment from which the counter-balancing weights are suspended, it is possible to regulate the transformer so that the current will increase or decrease as the number of lights is varied. The curves shown in Fig. 1 show the range of regulation that can be obtained by varying the adjustment of the cam supporting the regulating weights.

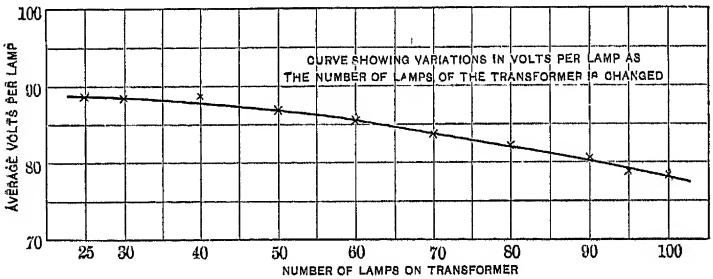


FIG. 2.

The early tests showed that when the transformers were adjusted to give a constant current through any desired range of load, that the lamps would draw different lengths on the arcs depending on the number of lamps on the circuit. The voltage across the terminals of the individual lamps was approximately 10 volts higher at one-fourth load than at full load, although the current was the same in both cases. The results of a test of a 100-light transformer made to show this effect is shown in Fig. 2. It has been found, however, that by varying the adjustment of the transformer, it is possible to adjust it so that the voltage across the terminals of the individual lamps remains practically constant at various loads. If so adjusted, however, the current from the transformer is no longer constant but increases as the load increases. The adjustment that maintains a constant voltage across the termi-

nals of the individual lamps seems the preferable one in those cases where the load of the transformer varies through a wide range. It is, however, of little practical importance in the operation of a street lighting circuit, as in that case the transformers are seldom operated in actual practice at less than 90 per cent. of full load.

Tests were made of the efficiency power factor and temperature rise of the transformers. The input and output of the transformers were measured with Weston wattmeters, ammeters and voltmeters, and were calibrated before and after test with standard laboratory instruments.

The averages of the results obtained from two 100-light transformers were as follows:

Load.	Efficiency.	Power Factor.
¼ Load	88.1	24%
½ "	92.3	44
¾ "	94.9	62
Full "	96.1	78

The rise in temperature of the oil of the transformer measured at the top of the iron core, where it was highest, was 39° C. after a twenty-four hour's run.

Under the usual conditions of street lighting, the dynamos are run under at least 90% of full load and at this load the efficiency and power factor are very satisfactory. The power factor is about as high as that of the induction motor under the average load at which they are operated.

The low power factor at fractional loads, and the difficulty in maintaining the lamps at constant voltage when the current is constant at various loads, combine to make the constant current transformer undesirable except when the conditions are such that it is possible to operate the transformer under a large part of its rated full load.

It has been found in practice, that the transformers can be maintained and operated successfully with very little attention. In Hartford five of the transformers are operated from two outlying sub-stations. There is no attendant at either of the stations. The inspector of the district cuts on and off the lights at the proper time and visits the sub-stations once during the night. Each transformer is equipped with a recording Bristol ammeter so that a complete record is made of the time of cutting on and off the circuits and of the time the inspector makes his nightly inspection, and of the working and adjustment of the

transformer. A record selected as being a fair representation of the daily records is given in Fig. 3. The primaries of the transformers are connected across the 2400-volt alternating current feeders. Although the voltage at the terminals of the primary of the transformer is subject to a variation of 5% during the street lighting hours, the current supplied to the series lighting circuits is practically constant. The transformer whose operation is recorded in Fig. 3, takes its current from the alternating

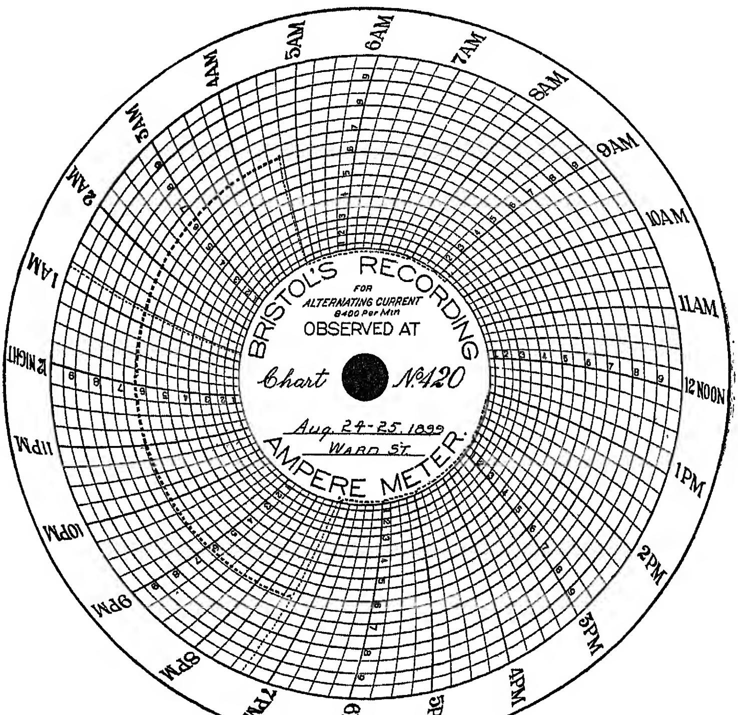


FIG. 3.

current lighting system about one mile from the central station. The current in the secondary is not affected by variations in the pressure at which current is supplied to the primary of the transformer.

THE SERIES ALTERNATING ARC LAMP.

The lamps operated from the constant-current transformer are of the carbon feed enclosed type. The alternating current used

has a frequency of 60 cycles. The operation of the lamp is on the differential principle.

The lamps at the outset gave a good deal of trouble. A considerable percentage of the lamps failed to start. This trouble was soon found to be due to the burning out of the sliding contact by which electric connection is made with the upper carbon. A positive contact is now made by means of a very flexible wire made of fine strands. Since this change the operation of the lamps has been in all respects satisfactory. The records show that the lamps reported out and not starting, are considerably less than they were when the street lighting was by direct-current series open-air arc lamps.

Unfortunately I have been unable up to the present to make any photometer tests of the candle power of the series alternating arc lamps. The lamps used in Hartford consume at the transformer 400 watts per lamp, and replaced nominal 1200 candle power open-air direct-current arcs. The streets are undoubtedly better lighted with series enclosed arc lamps than they were formerly with the open-air arcs. The better diffusion of the light from the enclosed arc lamp, the steadiness of the light and its freedom from flickering, have much to do with the improvement in lighting and with the general satisfaction it undoubtedly gives. From the results obtained at Hartford I am confident the streets can be better lighted with 400-watt series alternating lights, than with an equal number of nominal 1200 open-air direct-current arcs. If 2000 candle-power direct-current arcs were replaced by enclosed series alternating it would, in all probability, be necessary to increase the number of lamps in order to obtain equally good lighting.

Before the changes in the street lighting system the lamps were operated from Excelsior, Thomson-Houston and Brush series dynamos, belted from the line shaft. This was driven by a direct-connected synchronous motor. The power furnished the synchronous motor was 550 watts for each open-air arc lamp consuming 315 watts at the lamp. The power required under the local Hartford conditions for operating street lights has therefore been reduced by the change in the ratio of 550 to 400, or a little over 27%.

Owing to the fact that the transformers are operated from outlying sub-stations the wiring system has been very much simplified, and the cost of carrying current across the underground dis-

trict considerably reduced. The maintenance of the transformers and the labor in looking after their operation is an almost negligible item. A very considerable saving is made over the maintenance and operation of the series direct-current dynamo. From experience extending now over a year it has become evident that the saving in operating expenses will pay for the entire cost of the change in system within the first two years. At the expiration of this time there will be a very considerable annual saving, and at the same time the service rendered the city is very much better than it was under the old system.

The system of street lighting which will be found best for any given city depends largely upon the local conditions, but there are undoubtedly many cases where an investigation will show that the adoption of the constant-current transformer and the series alternating current arc lamp offers the greatest advantages.

Discussion.

The President :—We have had a good deal of experience up to the present time with constant potential transformers, but the constant current transformer is an apparatus with which we are less familiar, and an opportunity to study its behavior has been afforded us in the paper which Professor Robb has just read. There is also a good opportunity to examine the apparatus and I am sure that Prof. Robb will only be too pleased to help us arrive at its relative merits and demerits.

Mr. Charles P. Steinmetz:—An interesting feature mentioned in Prof. Robb's paper is the change of wave shape with the load. This illustrates the futility of specifying sine waves in alternating generators as occasionally done. It shows that the receiving apparatus is instrumental also in determining and changing the wave shape. This is especially the case with arc lamps.

As known, the alternating arc can not be represented by a constant effective resistance, but has an effective resistance varying periodically with the current strength, with double frequency. The apparent resistance of the arc is very high at small currents, low at large currents, and varies almost inversely proportional to the current strength. In consequence thereof, if the current passing through an arc lamp is a sine wave, the potential difference can not be a sine wave, but is less near large values of current, and greater near small values of current, that is becomes double-peaked, and if a sine wave of potential difference is impressed upon the arc, the current can not be a sine wave but is less near small, greater near large values of potential difference, that is becomes single-peaked.

Let us see now what takes place in a constant current transformer. At full load with primary and secondary coils close together, the internal self-induction is relatively small, and the secondary E. M. F. wave is nearly the same as the primary, that is assuming a sine wave of impressed E. M. F. the secondary potential difference is sinusoidal, thus the secondary current single-peaked. At light load, however, the primary and secondary coils are widely separated, and the internal self-induction of the transformer very high. Thus by the effect of self-induction in suppressing the higher harmonics, the secondary current is maintained closely resembling sine shape, and in this case the secondary potential difference becomes double-peaked. Thus from no load to full load the shape of E. M. F. and current waves in the arc light circuit changes, but in no case can current and E. M. F. have the same shape, for instance both be sine waves.

Since the instruments read effective values, the regulating mechanism of the lamp, however, especially the shunt coil magnet, depends to a certain extent on the mean value of potential difference; with the change of form factor under load, the lamp regulation may slightly change.

If nobody takes the floor I should like to add a few remarks on the rectifier which has never realized. This rectifier was a 60-cycle single-phase apparatus and operated extremely satisfactorily carrying 50 to 60 lamps with absolute steadiness, from a motor-driven alternator, until I put it on the circuit of an alternator driven by a single cylinder engine with rather poor uniformity of the rate of rotation, realizing that such condition would have to be met in single-phase high-frequency work. The result was that the rectifier never left the factory.

Since that time the conditions of application of such rectifiers have changed, and some are now in satisfactory commercial operation, one for instance in Brooklyn. In this the 25-cycle three-phase rectifier is supplied with power from large direct-connected alternators driving synchronous machines, that is of a very close speed regulation. Under these conditions the operation is perfectly satisfactory.

So you see we have two solutions of the problem of arc lighting from alternating circuits. Direct lighting by constant current transformers, and alternating lamps for circuits of 40 cycles and over, single-phase or polyphase, and lighting by rectifier and continuous current lamps for low-frequency polyphase circuits of 25 to 40 cycles.

Direct arc lighting at 25 cycles is not feasible, 40 cycles being about the limit, and rectification is undesirable on 60-cycle single-phase circuits, due to the pulsating nature of the rectified current.

If you put a continuous and an alternating ammeter and a continuous and an alternating voltmeter in such a rectified single-phase circuit and vary the load from short circuit to full load: at one extreme the ammeters fairly agree and the voltmeters disagree widely, then the disagreement of voltmeters becomes less and that of the ammeters more, and ultimately at the other extreme of load the voltmeters fairly agree and the ammeters disagree. But at any load the product of volts and amperes exceeds the watts by as much as 10 to 20%. The efficiency of the rectifying apparatus if calculated by volt-ampere output comes out too high by the same percentage.

MR. J. H. HALLBERG:—After considering Mr. Steinmetz's statement it seems as if in time we shall be able to take the alternating current by means of the rectifier, and succeed in getting a commercially successful direct current series arc-lighting system operated by the large alternating generators, and in that way gain all the advantages which we gain by the series enclosed alternating system.

By what Mr. Steinmetz says it seems as if it would be possible to produce a successful rectifier, and if it is, there certainly is in my estimation more chance for the commercial success of the direct current series enclosed arc-lamp, at the present time than for the series alternating current lamp.

We have produced direct current enclosed series arc lamps with an efficiency of 97.3 per cent. That is a remarkably high efficiency. It is produced by a shunt lamp and it will regulate within six to eight volts, from cold to normal temperature, which is probably 210° F. Of course, I have followed with great interest the series alternating system, but I have never as yet had a chance to practice in it very much on a large scale; but, from what I can learn, nothing but the differential lamp has been applied as yet commercially to this system. Why should it not be well to experiment a little more with the shunt system and put it practically on the market? It seems to me that as the lag current is a great objection we could materially decrease the same by using a shunt lamp.

My trouble with A. C. enclosed shunt lamps has been in *starting* the circuit. The moment we throw the full current on the circuit of shunt lamps, if we do not use a dash-pot, we rupture the circuit instantly, for the reason that all the arcs are struck instantaneously, and it strains the generator and the transformer. I experimented with a small dash-pot in connection with the shunt lamp and succeeded in starting slowly, but by using it I sacrificed somewhat the regulation of the lamp on account of the sluggishness of the dash-pot. In the designing of arc lamps I have always tried to follow the method of doing away with the dash-pot, for the simple reason that the dash-pot is one of the most troublesome, as well as vital, parts of an arc lamp. I have succeeded in producing an enclosed arc lamp of the shunt type for constant current, A. C. series circuits which seems to be practical, without a dash-pot. Now, would there not be some advantage in applying this type of lamp to a system? Not being thoroughly familiar with the constant current transformer I shall not enter upon that subject at all, but simply from the arc lamp standpoint it seems if we could reduce the lag current and raise the power factor, we would be able to do much better than at present.

I have never made a test on a General Electric A. C. series lamp, but I presume they must have considerable lag current in the series coils. If we could do away with the wattless current in the lamps, and if the transformer would still continue to regulate as well as it does now with the assistance of the series lamp coils, wouldn't it be a better system?

Mr. Richard Fleming:—I would like to reply to the gentleman's reference to the power factor of the different lamps. The power factor of the differential lamp as seen by the curve of the transformer at full load, is very nearly 80 per cent. The power factor of the feed lamp at 60 cyles is 92 per cent. The efficiency of that lamp—I cannot give you the exact percentage, but a lamp consuming 425 to 450 watts at the terminals consumed 10 to 20 watts in the shunt magnet and about 2 or 3 watts in the small cut-out magnet. So you can see that it has a pretty

high percentage efficiency. The variation which takes place due to the wave form, which I believe to be the cause of it, is altogether overcome by the use of the shunt feed lamp. The load can be changed down to short-circuit on the transformer and the lamp, even though the current may increase, say three-quarters of an ampere to an ampere, due to the fact that no regulation is provided down below quarter load, no change whatever takes place in the lamp—no change which can be measured on an ordinary alternating voltmeter. That is, to say the least sufficiently close. Regarding the operation of the shunt feed lamp, the variations of the volts at the arc can be maintained within three volts on a lamp ordinarily adjusted for about 73 volts to the arc. Some lamps, perhaps, will increase just at the feeding point or at the tripping point of the clutch. This particular lamp that I have in mind is so designed that just before the tripping point it reduces the arc voltage about two volts, and when the clutch gets on the tripping point at the moment of release the voltage at the arc has reached about normal. So that judging from these figures, the operation of the lamp should be satisfactory. Regarding the starting of shunt lamps, there is absolutely no difficulty. There are a great many thousand shunt lamps, direct current, in operation, and I do not think that they have ever been known to cause any great difficulty in starting, and I will make the broad statement that the alternating lamp with the constant current transformer will start equally well. Dash-pots, of course, we use. They are one of the necessary evils of the arc lamp business. I suppose you are aware of that. So am I. But I will say this, that I think the trouble with dash-pots has been overcome by close attention to details and care in their manufacture. I will say that a great many thousands of these dash-pots are out at the present time, and the particular style I have in mind are operating most perfectly; in fact, I have yet to hear of more than one or two out of several thousands that have given trouble, and that not of a serious nature. So that the dash-pot question is hardly to be considered. The starting of the transformer was also mentioned as being a disadvantage. But that is a very easy matter. It is easier if anything to start into operation than an ordinary series arc dynamo. You can start it on the ground, having it in a station or a sub-station, or you can start it at a distance. A device has been designed for the latter purpose that does it most effectively. Any further questions I should be glad to answer

MR. HALLBERG:—I can bear out Mr. Fleming's statements fully. My experience has been practically the same. The only particular in which we differ is in reference to the dash-pots. Of course, I realize that since the introduction of graphite and a few other such materials the difficulty may have been overcome to a certain extent. I did not mean that it is the actual effect of the

dash-pot which interferes with the regulation of the lamp. It is the natural move of the dash-pot, which is sluggish, and will cause the mechanism to hang up and work sluggish, that is,—cause four or five volts' variation at the arc.

I made, a year or a year and a half ago, 14 alternating shunt lamps. They operated in series on about 1100 or 1200 volts. In place of a transformer I used a regulator, and this regulator was constructed on the rheostat principle with small impedance coils across the segments, and the main solenoid connected in series with the circuit which automatically cut in or out these impedance coils. This system worked beautifully and with a very small wattless current. The efficiency tested out very highly and the regulation was perfect. The shunt lamp was used in this experiment. The only difficulty experienced was in starting the circuits, as the lamps were not provided with dash-pots. By use of a special starting device the lamps were started without chattering or breaking the circuit. Of course, we realize in a differential lamp the carbons are together when the lamp is at rest, and the moment you put on the current they lift gradually.

In the shunt lamp the carbons are apart when the lamp is at rest, and when the current is turned on the carbons are forced together. The arc is struck by means of either a spring or gravity. If no dash-pot is used, the carbons separate very quickly, and if a large number of lamps are in series, it might cause the circuit to break and the lamps would consequently chatter before starting. Would it be possible to start a series of shunt lamps without dash-pots on a constant current transformer?

MR. FLEMING:—I do not think it is advisable. It is possible. In fact I have operated a circuit of lamps without a dash-pot. But I will say this, that I believe the dash-pot is an improvement. On the point you raise of starting, however, it is possible to start without excessive chattering. We have operated lamps, as you say, across the terminals of an alternator by the use of a reactive coil, an apparatus exactly like a constant current transformer in which the coils are connected in series, which gives practically the same effect you mention. The effect would be the same. That operated well. We have not done anything with that to speak of for the simple reason that it has several disadvantages as against the constant current transformer. With the use of the constant current transformer it is possible to separate your arc circuits entirely from your primary mains having no connection electrically with your distribution system, and that without the use of an auxiliary static transformer.

MR. HALLBERG:—Of course I realize to the full extent the scientific piece of work we have on the platform, and I admire it. It is a beautifully working piece of apparatus, and I think it thoroughly practical. My only suggestion was the use of a shunt lamp.

Of course, in arguing these points we have a good many things to take into consideration. I am simply looking at it from the arc lamp standpoint. I have nothing to do with the transformer, and know nothing practically about it. I have tried to get hold of data and information in the last few years, but it has been rather scarce, and we had to do the best we could with what we had, and I think from what Mr. Fleming now states, it will not be impossible to see a nice shunt system in operation.

Mr. C. O. Mailloux:—I would like to ask Prof. Robb if they ever had any open circuits, and what happened then. We know that open circuits occur with direct current series arc lamps. I would like to know what happens when he has them with this transformer. Its E. M. F. will of course tend to rise greatly, and some precautions are doubtless necessary.

I was impressed with the uniformity of the current as shown by the Bristol chart records. I have had made many records of the same kind with Bristol recorders on direct current arc circuits, and I think you will all agree with me that they do not compare in uniformity and steadiness with those that are shown this evening. The direct current arc machine usually has a slight fluctuation. The current will rise a tenth or two above the normal ampere value, and it will fall a few tenths below, and sometimes it does that so fast and so often that the resulting line is a broadened mark which occupies a space corresponding to three or four tenths or even half an ampere. In this case you will see on the chart that the line is not greater in width than one-tenth of an ampere. In fact it is scarcely wider, if at all, than the width of the pen mark, showing that the current is maintained at practically a uniform and steady value. It varies at certain points, but the variation is slow. The charts show notches where the current value is raised as a whole or lowered as a whole. That may be due to lamps being cut out. Perhaps Prof. Robb can explain these notches in the curve.

Prof. Robb:—When the circuit opens, either one or two things happens. If it is simply an open circuit for example on the hanger-board, you can spring a cut-out across it, and the circuit will run through till next morning. Of course, if we have a line wire broken, the coils of the transformer immediately go together and you have the full voltage of the transformer in the circuit. In practice, we never have had any difficulty from that which amounted to anything. We never had any serious injury to any number of lamps arise from it. As regards those notches that occur in the curves quite frequently at times, I have noticed a slight change in the position due to the variation in frequency. I do not think, however, that is really due to a variation in the current, so much as to a variation in the recording device. As you all know, Bristol recording meters are very much affected by the frequency, and you will nearly always notice that when the ammeter is thrown in or out of circuit it comes back slightly

different on the Bristol ammeter. I think they are largely inaccuracies in the recording device--hysteresis of the recording device.

There is one point in connection with the operation of transformers where we expect to meet with difficulty in connection with the operation from sub-stations. Of course, it will happen in every station if your circuits go out. In fact we have had a difficulty which has annoyed us a good deal in the past. Our circuits are rather freely equipped with lightning arresters. On the alternating system we run large units with separate lightning arresters at each transformer, and we find, now that we have probably back of the system about 4,000 horse power, that after a severe stroke of lightning, if there is a rush of current it blows the fuses on the circuits. It has happened in those cases at times when fuses have gone on the particular circuits on which the sub-station was. But we simply throw the switch in the station and let it go; it goes all right, operating perfectly satisfactory under those conditions. I think there is one point that Mr. Fleming brought out which is a very important one, and that is, that in the operation of street circuits, the fact that any system to give satisfactory operation must have the street lighting circuits separate from the alternating current distribution. That is, if you use any other regulating device you must have a static transformer between the two systems, owing to the fact that in the operation of series circuits they are sure to be more or less grounded. It may interest Mr. Steinmetz to know that I made a test of the transformer, giving the results of regulation, not the particular curve that I showed this evening, but I got another which was practically the same, and also measured the wave-form of the electromotive force given by the generators, and it was almost a perfect sine curve, simply one harmonic present to a very small percentage, and the result is very much the same.

Mr. Steinmetz is much more encouraging about rectifiers this evening than he was two years ago. Two years ago the rectifiers worked beautifully. The only trouble was, I was invited to see the operation of a rectifier, and I waited fifteen minutes to see it start. The rectifier worked beautifully. I tried to bring out that what is good practice in one locality is not good practice in another. There are a great many circumstances in which it is not advisable to use as low a frequency as 25 cycles. Furthermore a system which will pay for the total installation in two years can be very readily changed when we get to rectifiers. If we get the rectifier and find it does not work satisfactorily we can change it. It does not pay to stick to motor-driven direct-current machines with the possibility that in two or three years we may be able to get rectifiers, when we can put something in the place of them that will pay for itself in the course of eighteen months or two years.

MR. STEINMETZ:—I do not want to be misunderstood. I wanted to bring out that both types of apparatus have their proper field of application, the rectifier for 25-cycle power distributions where the constant current transformer is not feasible, because it gives too low a frequency for arc lighting, while in a 60-cycle system by the use of a constant current transformer we can dispose of the rectifier. The rectifier finds the proper field in the 25-cycle system.

PROF. ROBB:—I think we agree perfectly.

MR. STEINMETZ:—We have heard a good deal about rectifiers abroad, and how beautifully they are operated, and have heard reports of tests of very high efficiencies. For that reason I referred to the power factor of the rectified circuit, since I suspect that some unusually high efficiency claims are due to measuring the volts and amperes, multiplying them with each other and calling that the output.

MR. FLEMING:—In regard to the question of operating arc lamps on 25 cycles, I will say I have made an enclosed arc lamp, and operated it to a certain degree of satisfaction on 25 cycles, and I believe that it is not at all impossible to operate these lamps at that frequency, especially for street lighting. It is not a pleasant light to look at. But we do not look at the sun ordinarily as we pass along the street. We do not look at the arc lamps either. At a distance of 50 to 100 feet the light is not bad. It flickers: you can see that disagreeable trembling of the arc, but for street lighting I believe it can be made a commercial success, where it is not necessary to have the great refinements of smooth, even lighting. Take it all in all, I believe that if I were operating the station I should prefer the 25-cycle arc outside, to a rectifier inside. At 40 cycles the alternating arc is perfectly satisfactory for street lighting, and anywhere from that to 140 which is about the limit of commercial frequency.

The question was asked, "what happens when the circuit opens on a constant current transformer?" The total secondary electromotive force is applied to the break. Recently I have devised a little cut-out that when such an accident occurs, will immediately open the circuit at the station, and short-circuit the secondary of the transformer. This can be made to give an alarm. If the transformer is in the station it will generally give its own alarm to a certain extent. It will move and can be seen by the attendant, but as a matter of fact constant current transformers are generally installed in a basement or similarly out of sight. But it is a simple matter to rig an alarm that will indicate an open circuit on the line.

A gentleman mentioned the fact that if rectifiers were possible it would be very advantageous to use D. C. lamps as against A. C. lamps. There is a good deal to be said on both sides of the question. In my mind there is no advantage in using the D. C. as the A. C. is equally effective if not more so, especially for street

lighting, as with two lamps, assuming an equal amount of energy, the arc alternating lamp would be more satisfactory for street lighting and equally satisfactory for inside lighting. I think I can illustrate what I mean by a diagram. [See Fig. 4.)

If an arc lamp is suspended 25 ft. from the ground the relative distribution of light will be about as shown. Curves A and A′ represent approximately the curves of distribution of an alternating lamp, enclosed type; B and B′ show the distribution of light from a D. C. enclosed lamp while C and C′ give the characteristic curve of an ordinary open arc D. C. lamp. The curves of the enclosed lamp in both cases represent lamps equipped with reflectors as used for street lighting. It will be noticed that the open arc lamp has a much higher maximum at an angle of 45°

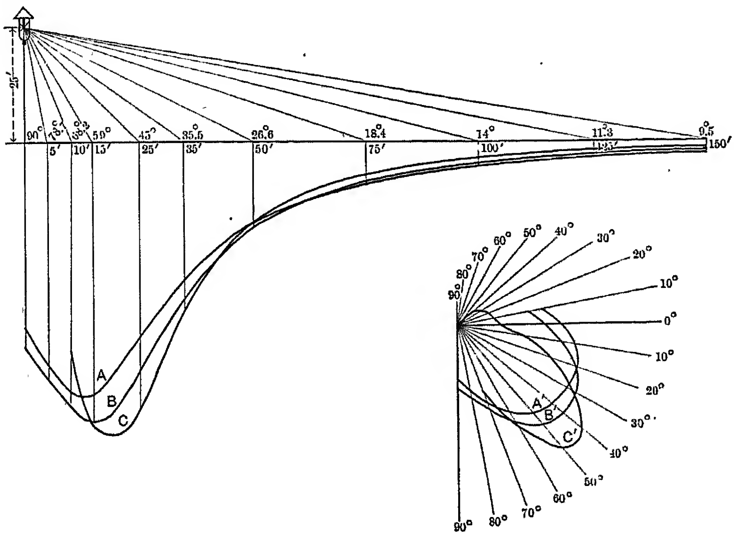


Fig. 4.

below the horizontal, and by referring to curve C (which is plotted according to the law that the amount of light is inversely as the square of the distance), it will be seen that this angle represents the distance from lamp of about 25 ft. At this point the illumination is much better from the D. C. lamp, open arc type, than from either of the others. At this angle the D. C. enclosed lamp comes second, while the alternating lamp is less than either.

At an angle of about from 25 to 30° below horizontal, the three lamps give illumination very nearly equal. This represents the distance from the lamp of about 50 ft. Beyond this point the light from the open arc lamp falls off very quickly. The D. C. enclosed lamp much less so, while the alrernating lamp gives more light than either. By referring to the curves it will be seen that at an angle of 10° below horizontal the alternating lamp

gives nearly twice as much light as the D. C open, while the D. C. enclosed is intermediate between the two, and approaching the alternating in luminosity though not quite reaching it. An angle of 10° below the horizontal represents a distance of very nearly 150 ft. from the lamp, at an elevation of about 25 ft. from the ground.

It should be noted here that the open arc lamps should be suspended as high as possible while the enclosed arc lamps should be hung as low as permissible. The usual practice in this respect is 20 ft. from the ground.

On account of characteristic distribution of light from the alternating lamp it is almost ideal for street lighting and especially where the distance between the lamps is considerable. Where lamps are installed more than 100 feet apart the general effect from an alternating lamp for the same amount of energy consumed at the arc will be superior to any other.

To test the above in actual operation, an installation has been put up to determine the relative merits of the different lamps by making a comparison side by side. In the installation referred to, a number of the different kinds of lamps have been hung in a large open field at a measured distance apart and in such a way that comparative estimates could be made of the amount of light given by each lamp under actual commercial conditions.

As a result of these tests, a great many who were skeptical as to the merits of the alternating lamps have become convinced that the alternating enclosed lamp is equal if not superior to its older competitors in every way. The most important thing about this lamp is that the light is thrown exactly where it is wanted. The D. C. enclosed lamp approaches it quite closely in this respect but it is in no way superior. Either lamp is far superior to the old style open arc lamp.

I recently saw a photograph made in St. Louis to determine the relative amount of light given out by a 9.6 ampere D C. open arc lamp as against a 7½ ampere alternating enclosed lamp. Both lamps were adjusted to consume approximately the same number of watts at the arc.

A sign was made up especially for the occasion with white letters of varying height on a dark background. The sign was placed about 100 ft. from the lamp and a photograph made by means of the light from each lamp. On the photograph from the D. C. lamp the foreground was brilliantly lighted, while half way between the camera and the sign, the light stopped short. Beyond this point it could be very plainly seen that there was comparative darkness, it being barely possible to make out the outline of the sign and letters, and the surrounding buildings and other objects were represented by mere shadows.

With the alternating lamp it was quite different, not only was the sign well lighted, but the buildings were lighted up quite well, and a number of advertising signs could be clearly made

out. The foreground was not nearly as brightly lighted as with the D. C. lamp but the photograph shows an almost perfect distribution of the light to a considerable distance from the lamp. The exposure in each case was identical and the development purposely made the same, and everything possible was done to make the conditions equal. The exposure was about 20 minutes with the diaphragm of the lens set at F-16.

MR. HALLBERG:—When I made a remark in regard to the advantage of the direct current lamp over the alternating, I had reference to the *enclosed* direct current lamp. But, of course, now that Mr. Fleming has stated that the test was made on open arcs, I realize with the short arc it would not compare favorably at a distance with the alternating long enclosed arc. But if we take a direct current arc at 70 volts enclosed, at 6½ or 7 amperes and another of the same amperage and voltage at arc, on alternating current, we have two different cases,—one represents an arc approximately five-sixteenths of an inch in the direct current enclosed lamp. On the alternating current enclosed lamp we have an arc that is seven-sixteenths of an inch long. That bears out Mr. Fleming's idea of the distribution of the light. Where do we get it? In the alternating current we get the light from the arc itself;—we get very small craters on the alternating lamp, on account of interruptions on the circuit, depending upon the number of alternations, the light is practically extinguished as many times a minute as the alternations change. On the direct current enclosed lamp on the other hand, we have also got a long arc. The arc is much whiter than that of the alternating lamp, and in addition we have a crater on the upper carbon. I have not had a chance to investigate these tests which Mr. Fleming speaks of, and scientifically I have never had a chance to trace the curves or make a photometric test of them. But practically, I think that the direct current enclosed lamp will still hold its ground over the enclosed alternating, as far as illuminating power per watt is concerned.

Another little matter that figures very much in favor of the direct current lamp for the central station is, that the life of the direct current lamp is probably 125 to 150 hours, and the deposit on the inner globe at the end of that number of hours is no more than it is on the alternating lamp, which will only give a life of 75 hours. The carbons for the alternating lamp cost, if anything, more than they do for the direct current lamp. When we sum the two together, I still believe that the direct current enclosed arc lamp to-day holds the ground over the enclosed alternating lamp, providing the arc takes the same voltage and the same amperage, and if I should suggest a successful street lighting with alternating current, I should try to employ 7 to 7½ amperes.

MR. FLEMING:—Regarding the amount of light of the alternating and direct current enclosed lamps I have tried to show there, I did not bring out the merits of the direct current en-

closed lamp as fully as I might. The total difference in light between the D. C. and the alternating enclosed lamp is roughly about 10 or 15 per cent—I say roughly, advisedly, because we can only measure it roughly—it is about 10 or 15 per cent. in favor of the D. C. lamp. One thing that operates to the disadvantage of the D. C. lamp is the length of the arc. A D. C. lamp operating at 70 volts has a comparatively short arc, so short that the shadow thrown by the lower carbon is very pronounced. This can be shown by the band of light on the inner globe. There is a band around the enclosing globe at an angle below the arc, whereas with the alternating arc the distance apart of the ends of the carbon is quite great. In that way the light has a good opportunity to get out, and the shadows are not nearly so pronounced. The shadows of the carbons in the alternating lamp are not more than the necessary shadows thrown by the frame, and by the parts of the lamp itself. That 10 or 15 per cent. in favor of the D. C. lamp is more than made up by the curve of distribution of the light from the alternating lamp. That is, the maximum light is actually where it is needed at a distance, and not directly under the lamp. The alternating lamp is almost ideal in that respect, and has a great advantage over the D. C. lamp.

Another point of the alternating lamp—we all know that the negative carbon on the D. C. lamp is not consumed rapidly, and the arc remains practically in the same place. On that account the deposit on the globe is all located on the upper part of the globe, and after a while the drop in candle power is very pronounced. On the other hand with the alternating lamp the arc travels down—I do not exactly remember the relative proportion—several times as great—it is continually moving down into the cleaner portion of the globe. That is a fact that I have proved by actual photometric tests, and is very much in favor of the alternating lamp. It leaves the deposit on the top of the globe, and is continually moving down so that the light gets out under this deposit. That was suggested quite a while ago. I made tests to prove it, and I have on record a photometric test showing where an alternating lamp at an angle of about 45 degrees, I think it was, gave actually more candle power at the end of an 80-hour run than it did with a clean globe. That is putting it rather strong, but such is the fact. That is on record. That was due to the fact that the white, fleecy deposit which is so characteristic of the alternating arc, due I think, to the core, acted as a reflector and threw the light down, which was what we wanted, and the curve from that lamp at the end of the run was something like that of the D. C. lamp showing that the light upwards was cut off to a marked extent, while the light downward was increased, owing to the reflection from the inside of the globe and I think it is perfectly reasonable. Regarding the cost of carbon, there is very little difference between the two. The cost of trimming is about the same.

The current at the arc is a question which central station men will have to govern. It will have to be governed by local conditions, though I will say that a 6.6 ampere alternating lamp will hold its own against the nominal 1200-candle open air arc, and that the 7½ ampere lamp will more than hold its own against the nominal 2000-candle arc, or against the 6.6 or 7-ampere direct-current enclosed lamp.

Mr. Hallberg:—As regards the shadows of the enclosed direct current lamp: I think that this has been pretty well overcome by the means of suitable reflectors. We have had some very severe tests on this point, and found that absolutely no shadow would be shown under any of the lamps provided they were all equipped with the proper reflectors. As regards the weakness of the shadow with the enclosed A. C. lamp, it is caused by the weakness of the alternating arcs as compared with the direct arcs. The absence of a crater in the alternating arc is what accounts for the fainter shadows with the alternating than with the direct enclosed lamp. When we come to the matter of deposit on the inner globe, my experience has been that on the direct current the deposit travels up. On alternating current it fills the entire globe more evenly. If we take two globes, one direct and one alternating, at the end of their runs you will find that the direct current globe has got a very marked dark circle around the top, whereas the A. C. globe will have a much more even coating on the inside.

As regards the travelling down of the arc; of course, the alternating arc travels much more rapidly, because the carbons are consumed 50% quicker.

In regard to Mr. Fleming's statement that he obtained more candle-power out of an A. C. enclosed lamp, after 70 hours' burning than he did on the start of the run, I cannot argue this point as I was not present at the test, but it must be remembered that he admitted that the deposit followed with the arc, slightly behind it, consequently at the end of the run this deposit prevented a large percentage of the light, which should have been thrown up against the reflector, from being utilized. It should also be remembered that the upward rays of the A. C. lamp were put down as being strongly in favor of the A. C. lamp. According to this, after the A. C. lamp had operated a short time, we would sacrifice this good point.

The D. C. lamp gives double the life and needs less attention. I think that it is of more importance to a station to have a lamp that runs 125 to 150 hours than to have one that will run only 70 hours. It means 50% less labor in trimming.

For conclusion, I beg to say that it has been generally admitted that the D. C. arc is more powerful and more suitable for illumination than the A. C. arc, and until some new feature is brought out in favor of the A. C. system, it will be hard to convince the central station manager of its superiority, especially if we can produce a successful rectifier for the D. C. arc-lamp.

Mr. Mailloux:—I would like to move a vote of thanks to Prof. Robb for the very interesting paper which he has given us. It is a new revelation in street lighting, and I think that he has made out his case particularly well, when, besides showing the material success of the lighting he has also demonstrated that the economic results indicate that the plant will pay for itself in two years or less.

The motion was carried, and the meeting adjourned.

[CORRESPONDENCE—SUBJECT TO REVISION.]

COST OF ARC LIGHTING.

BY H. H. WAIT.

[A communication in discussion of a paper by William Lispenard Robb, on Series Arc Lighting from Constant Current Transformers, read September 27th, 1899. New York and Chicago.]

The tables in this paper, giving the comparative first cost and operating expenses of various arc lighting systems, were originally compiled in a rough form some little time ago in order to determine whether it would pay to build a large direct current arc machine suitable for direct driving by moderate speed engines. The subject has received some little attention lately, and it was thought worth while to complete the tables and submit them to the INSTITUTE for discussion.

In Prof. Robb's paper on the Hartford system of arc lighting, a comparison is made between a modern alternating current system and an old direct current system. Several other such comparisons have been published recently. It is obviously unfair to compare an antiquated direct current system with the latest type of alternating apparatus. In the tables an attempt has been made to compare the systems given on an equitable basis. A little more attention has, perhaps, been given to pointing out some of the failings of the alternating current systems, principally on account of the fact that such systems are more or less of a fad at the present time and their failings not so well-known, whereas there are very few electricians interested in the subject who could not discourse for hours on the failings of older forms of direct current systems. In referring to the alternating current systems as fads, the intention is not to convey the opinion that the A. C. systems will not survive permanently, or that they are not considerably better than direct current systems for a great many cases.

Prof. Robb makes the statement that the changes in the Hartford plant will pay for themselves in about two years, and it would appear from the tables that in some cases the more modern continuous current systems might replace older ones and pay for the changes in still less than two years. This question is so dependent on local conditions, however, that it is impossible to make any general statements.

It is hoped that the tables are in such form that an engineer can pick out several systems to compare for any given plant and avoid the labor of going through the entire subject.

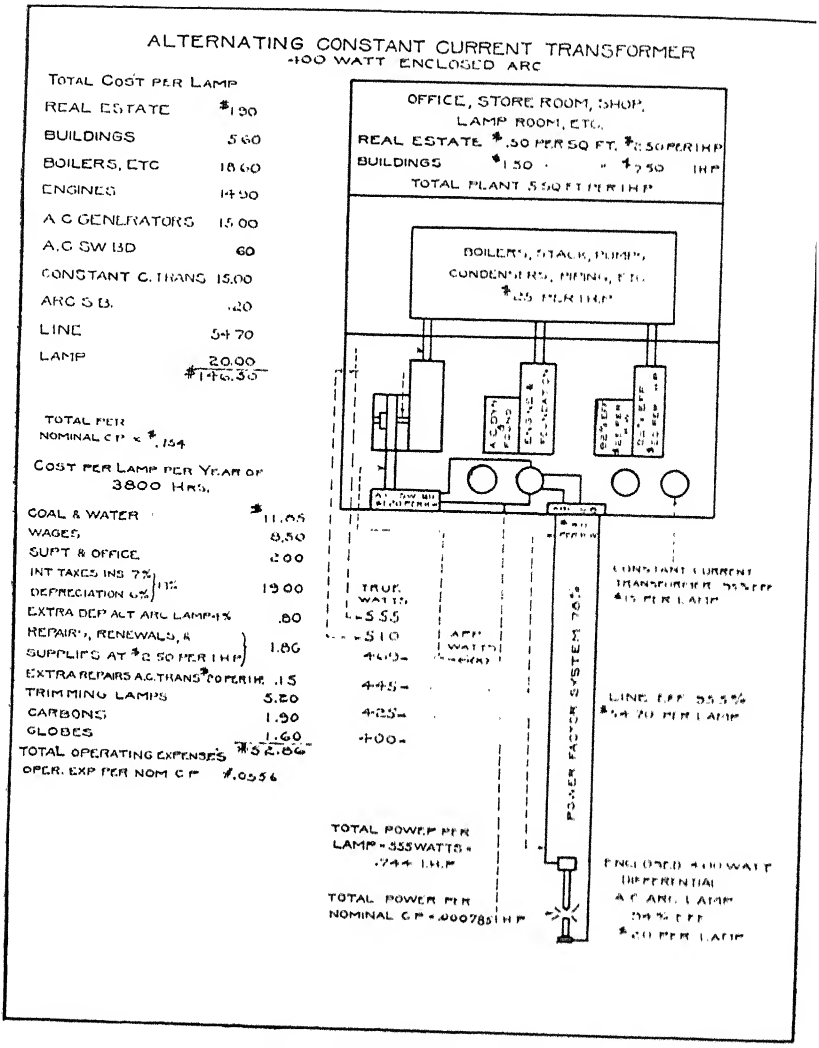


FIG. 1. 950 Nominal c. p.

NOMENCLATURE.

In the tables the following letters have been used with the corresponding signification. It might be well to remark that it would be desirable to have the INSTITUTE sanction some such use as there is considerable confusion in the use of similar letters at present.

A. C. ....Alternating Current
D. C. ....Direct Current.
D. D. ....Direct Driven.
C. C. ....Constant Current.
C. P. ....Constant Potential.
c. p. ....Candle Power.

ALTERNATING CONSTANT CURRENT TRANSFORMER
450 WATT ENCLOSED ARC.

Total Cost per Lamp.

Real Estate..........$	2 05
Buildings	6.16
Boilers, etc...........	20.50
Engines.	16 45
A. C. Generators.....	16.60
A. C. SW BD........	.78
Constant C. Trans....	15.00
Arc SW. BD..........	.20
Line	57.50
Lamp.................	20.00
	$155.24
Total per nom c.p....	.1349

Cost per Lamp per Year of 3800 Hrs.

Coal and Water..........$	13.10
Wages..................	9.35
Supt. and Office..........	2.00
Int. taxes, ins. 7% } Depreciation 6% } 13%..	20.20
Extra Dep. Act Arc Lamp 4 per cent.............	.80
Repairs, renewals, and supplies at $2.50 per I. H.P.	2.26
Extra repairs A.C. Trans. $ .20 per I. HP........	.18
Trimming lamps.........	5.86
Carbons..................	2.30
Globes	1 80
Total operating expenses.$	57 85
Oper. Exp. per nom. C.P..	.0503

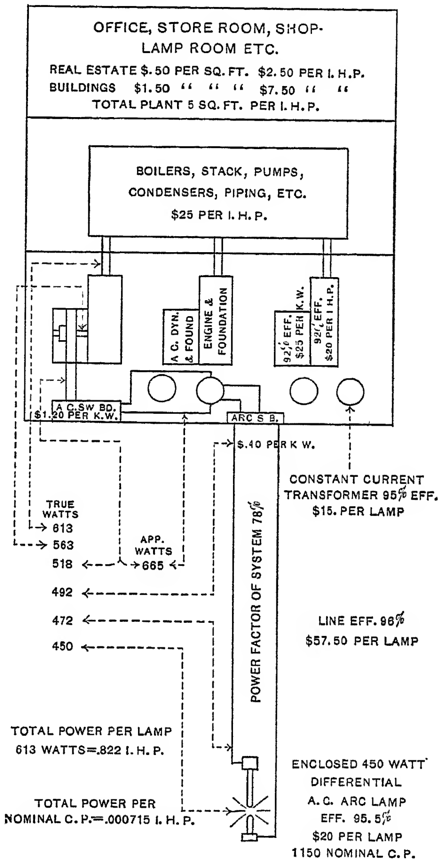


Fig. 2.

The vital question in comparing alternating and direct current systems is the relative amount of power consumed for the same amount of light. There is a great diversity of opinion on this subject and good authority can be found for all sorts of factors.

In the tables the different types of lamps have been given the following ratings for the sake of comparision:

D. C. open arc,	450	watts	at	arc,	2000 c. p.
D. C. enclosed arc,	450	"	"	"	1500 "
A. C. enclosed arc,	450	"	"	"	1150 "
A. C. enclosed arc,	400	"	"	"	950 "
D. C. open arc	300	"	"	"	1200 "
D. C. enclosed arc,	300	"	"	"	900 "

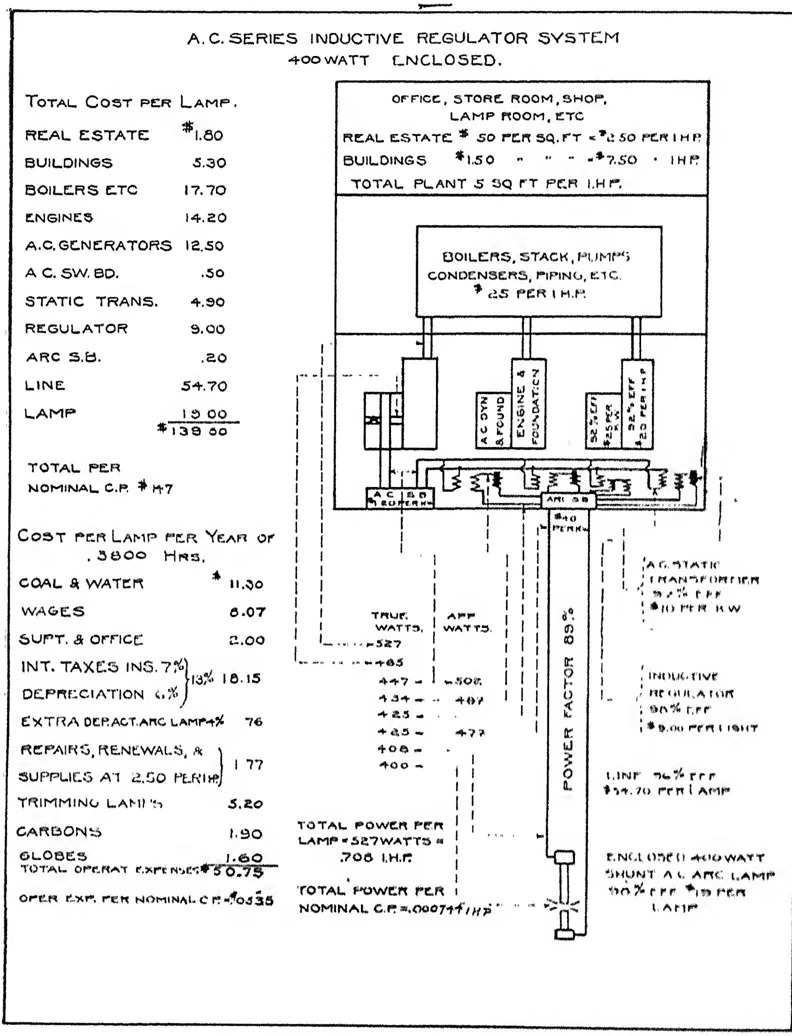


FIG. 3. 950 Nominal c. p.

It is unfortunate that the 2000 and 1200 c. p. ratings of 450 and 300 watts respectively, adopted by most plants do not refer to the watts at the arc, but seem to include some small loss in

the mechanism. It has been thought advisable for the sake of definite comparison to give these ratings to open arcs, the watts being taken at the arc itself and corrections being made for the relative efficiency of the mechanism for different types of lamp. To arrive at an equitable figure for comparing the enclosed A. C.

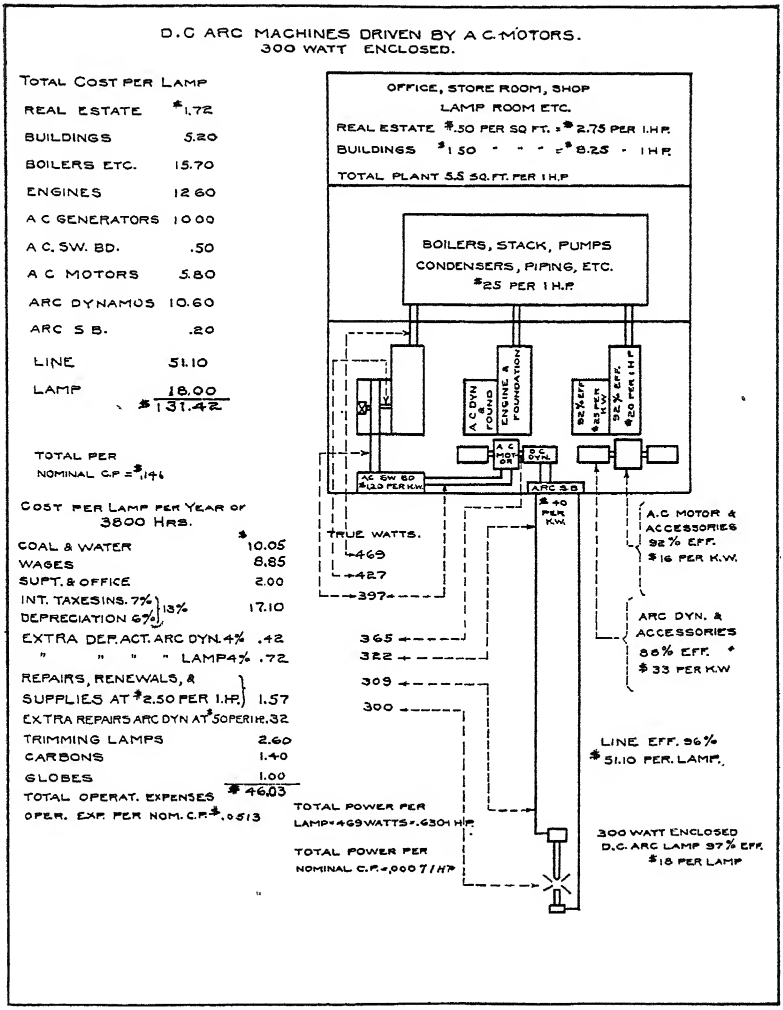


FIG. 4. 900 Nominal c. p.

and D. C. lamps with the open arcs, resort has been made to an average of the information at hand on this subject. In comparing direct current open and enclosed arcs the following figures were used:

				Ratio.
E. Thomson, *Elec. World*, June 12, '97,	W. per m.s.c.p.	open arc,	1.2	.69*
" " " " "	"	enc. arc,	1.74	
L. B. Marks, " " Feb. 6, '97,	"	open arc,	.95	.815
" " " " "	"	enc. arc,	1.17	
Pierron, *Elec. Review*, Mar. 5, '97,	"	open arc,	.577	.65
" " " " "	"	enc. arc,	.886	
L. B. Marks, Elec. Congress '93,	"	open arc,	.84	.72
" " " "	"	enc. arc,	1.17	
W. D. Steel, Street Test.				.82
General Average,				.739

This ratio is practically 75%, the value used in the tables.

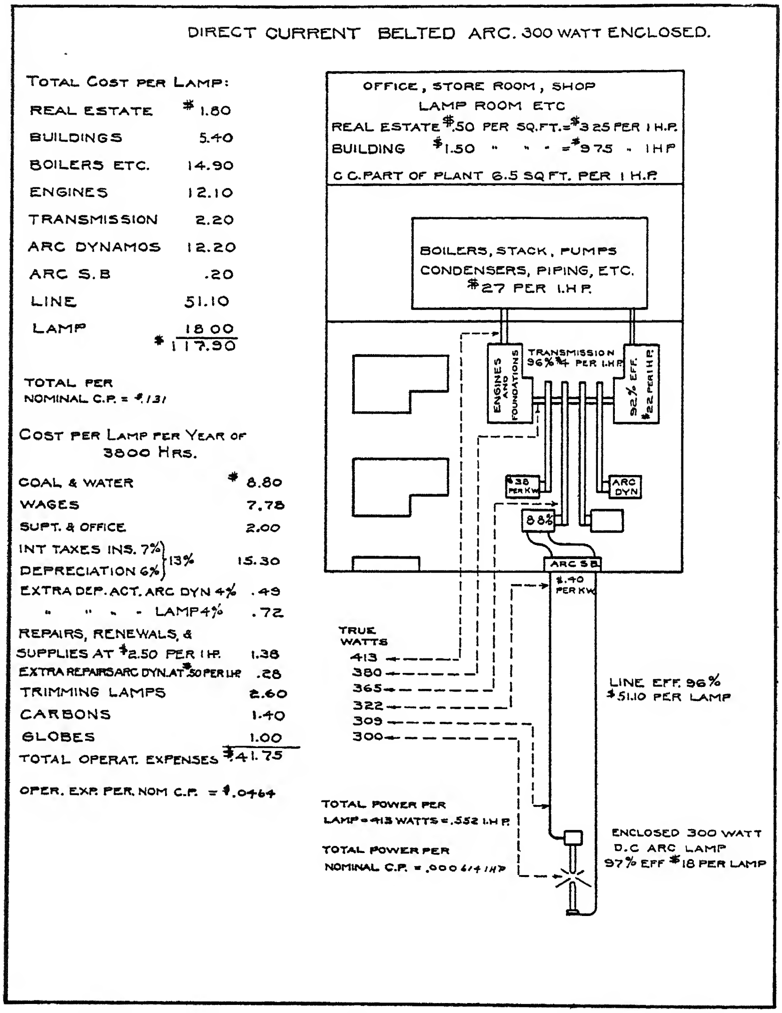


FIG. 5. 900 Nominal c. p.

*The value given is 1.94 at end of run; assuming that the average absorption of the globe would be 10% less, gives the figure taken.

If the mean hemispherical candle powers had been taken, the ratio would have been more advantageous to the open arc, but the distribution is so much more even with the enclosed arc that the lighting is generally more serviceable and consequently the mean spherical values were thought to give a reasonably fair basis of comparison.

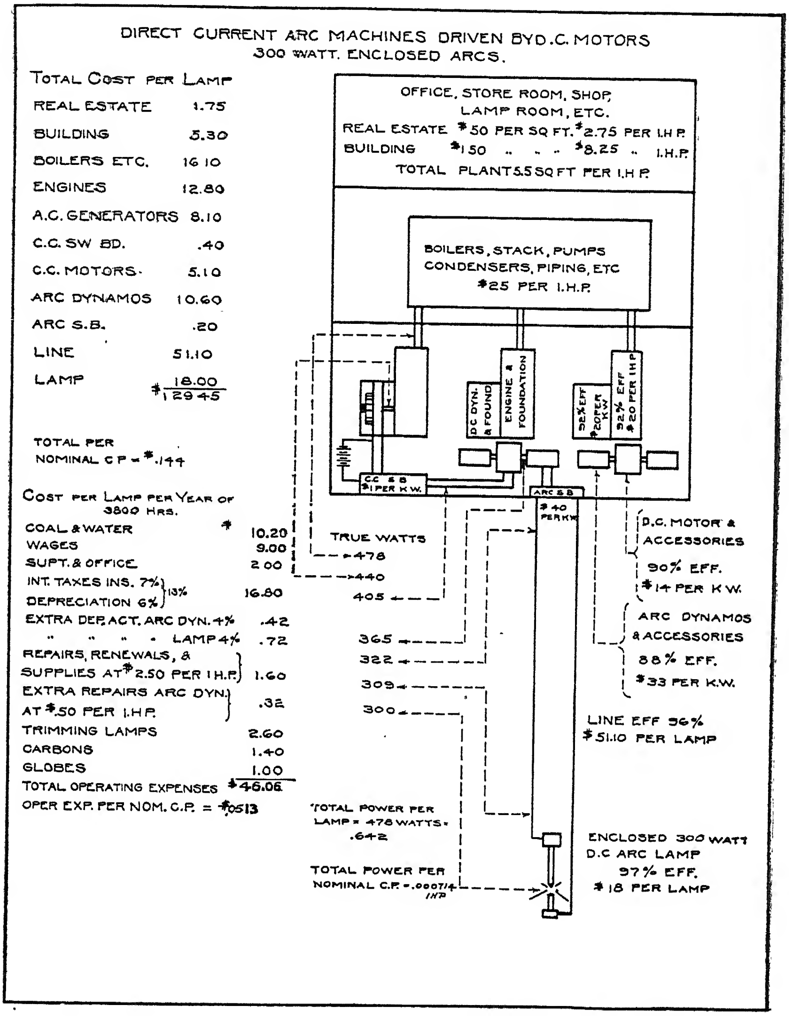


FIG. 6. 900 Nominal c. p.

For commercial lighting in stores, the superior distribution and steadiness of an enclosed arc undoubtedly give it so many advantages that for these cases it should be rated on a par with the open arc. For street lighting, however, the volume and intensity

of the light are more important than the quality, and as the tables refer more especially to systems serviceable for street lighting, the above ratio was taken.

There is very little reliable information at hand for comparing A. C. and D. C. enclosed lamps. The ratio was obtained as follows:

	Excess Watts per m.s. c.p. for A. C. over D.C.
Matthews, *et al*, TRANSACTIONS 1898, pages 605, 615,	52
L. B. Marks, Discussion of above, page 724	35
E. Thomson, *Electrical World*, June 12, '97, correcting for blackening of globe	21
W. D. Steel, Street Test	27
Western Electric Co., Laboratory Test	39
Average	34.8

33⅓% has been taken as a convenient ratio.

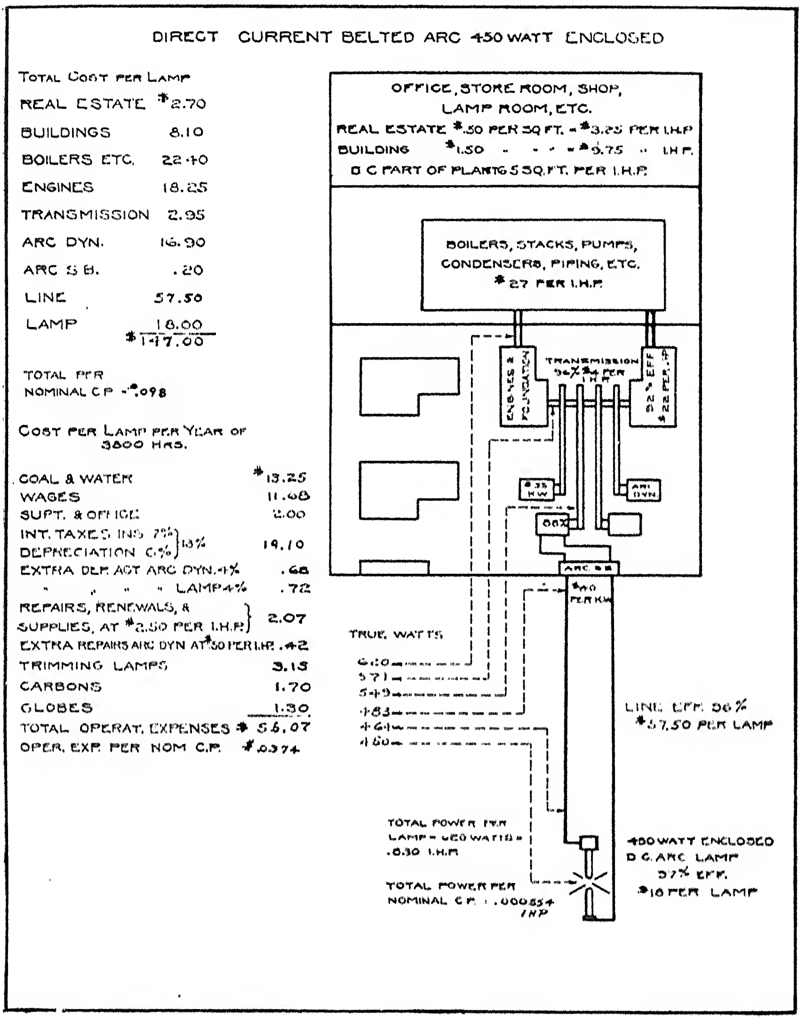


FIG. 7. 1150 Nominal c. p.

From the above ratios it will be seen that if 1200 c. p. is a fair nominal value for a 300-watt open arc, the enclosed D. C. might be called 900. A 300-watt A. C. enclosed would be approximately 675, and a 400-watt increased in the ratio of the watts would give 900. The candle power would undoubtedly increase more than in the ratio of the watts, and 950 has been taken as a mean value

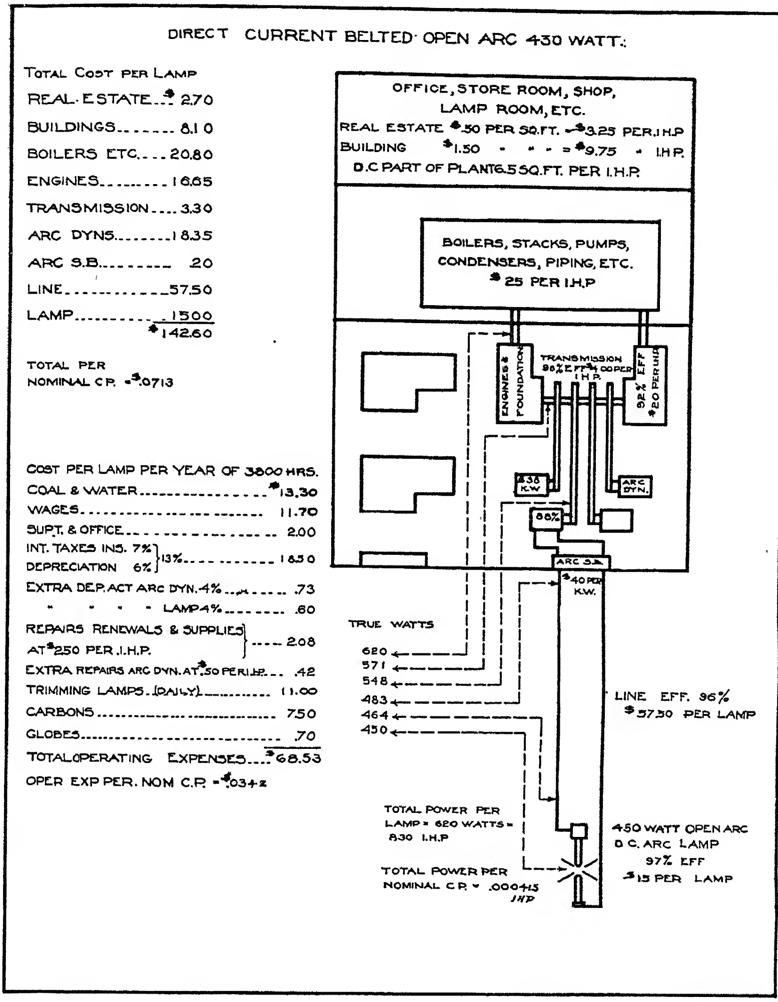


FIG. 8. 2000 Nominal c. p.

in working up from the 1200 c. p. open, and down from the 2000 c. p. open D. C. The resulting costs have been divided by all the nominal candle powers so that the cost can be compared readily at any reasonable rating.

It is only recently that much attention has been paid to the distribution of light at different distances along the street. The alternating current lamp with its maximum illumination near the horizontal plane has advantages in this respect. To get the full benefit of this feature of the lamp, it is necessary to suspend the lamp somewhat lower than has been customary with continuous

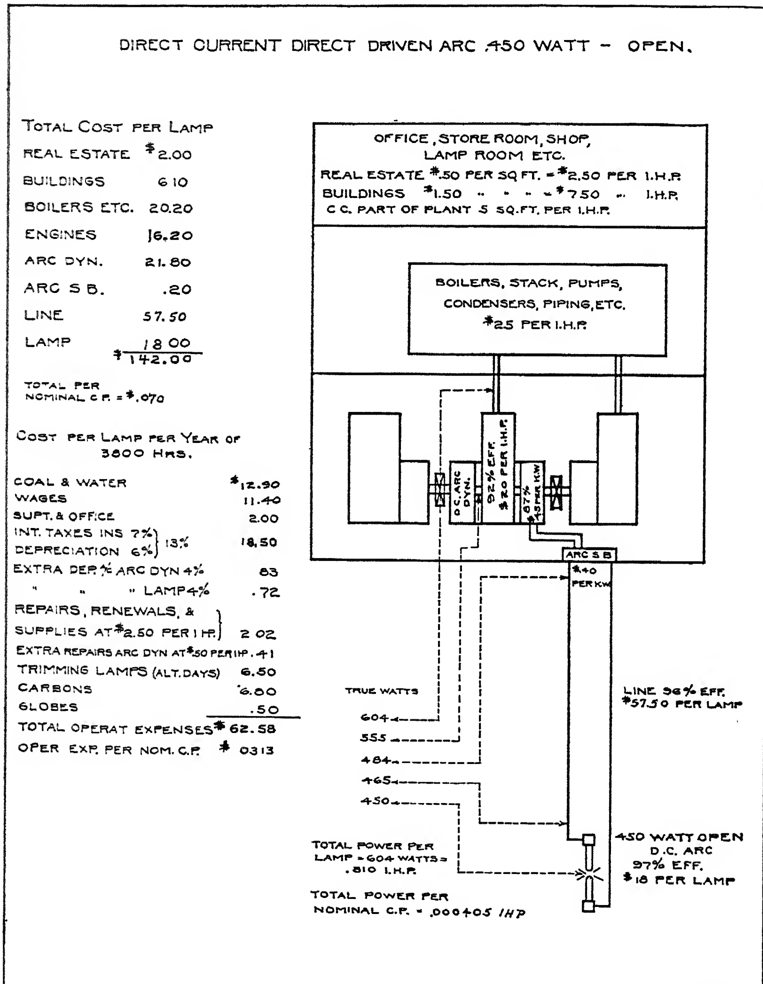


FIG. 9. 2000 Nominal c. p.

current lamps. This brings out a feature which is worthy of consideration, namely, the effect of the direct rays on the eyes of the pedestrian or observer. For example, assuming that the illumination of objects from two lamps was equal when the observer was looking in the opposite direction from the lamp;

suppose that one of the lamps was placed quite high and the other nearly in his line of vision when looking towards the lamp; it is quite evident that whereas the illumination of objects is equal, the perceptive power of the pedestrian is decidedly impaired by the glare of the low hung lamp and he is not only less able to

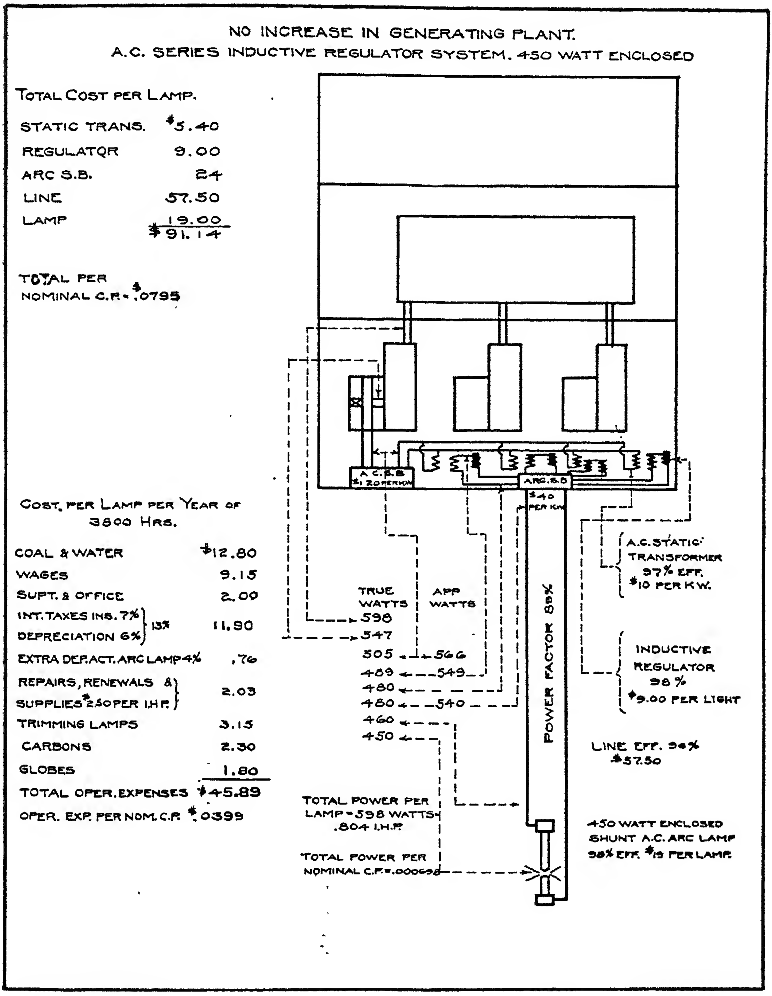


FIG. 10. 1150 Nominal c. p.

perceive his surroundings but would also be considerably annoyed if the lowering of the lamp were carried to extremes.

It is also in order to call attention to the fact that if it is allowable to use reflectors to save the upper hemisphere of light in the alternating lamp, the direct current lamp should have the privi-

lege of using reflectors or other devices to reflect some of the maximum rays so as to throw them in a horizontal plane, if that is the direction in which illumination is desired. Some of the globes in present use have considerable of this effect.

Another factor in this comparison is that of color, the alterna-

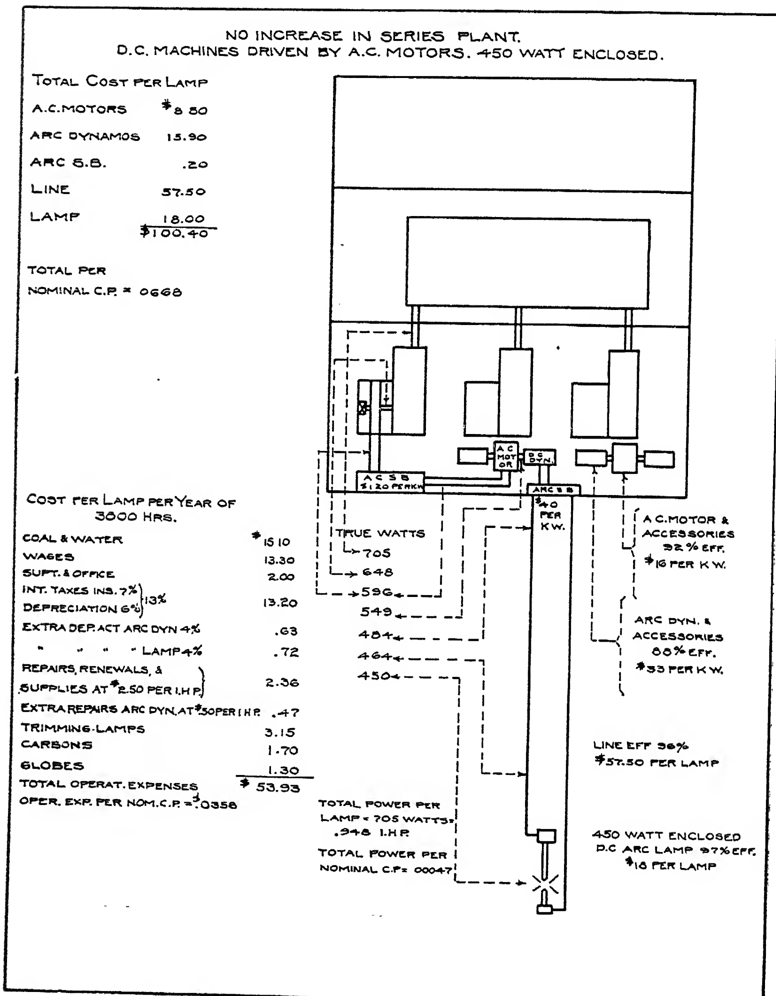


FIG. 11. 1500 Nominal c. p.

ting lamps generally having a larger amount of violet rays. Under certain circumstances this would be an objection, and it should also be noted in this connection that photographic studies of the relative illuminating powers of arc lamps are liable to be very greatly in error on account of the superior actinic value of the violet rays.

The tables are all made out assuming that the arc lighting part of the plant to be running at very nearly full load whenever it does run. This will, of course, not apply to commercial lighting circuits, and considerable corrections will have to be made for such conditions. The following points might be mentioned in this connection.

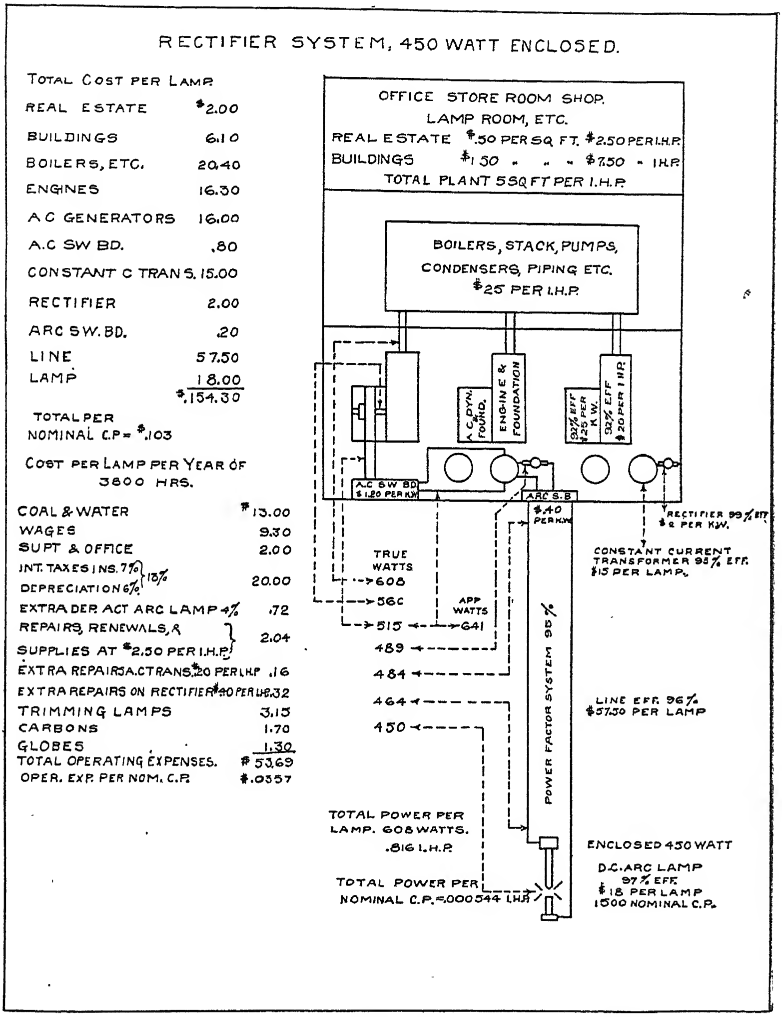


FIG. 12.

The continuous current generators will fall off quite rapidly in efficiency as the load goes down. The engine efficiency will also fall off in the case where the machines are operated directly from the engines until the load is sufficiently reduced to permit shut-

ting down one of the engine units. Some A. C. systems have the disadvantage that it is not practicable to operate them at all on very light loads, but the efficiency is not very greatly reduced at light load although the decrease in efficiency of the system is augmented by the fact that the power factor runs to quite low values at the light loads.

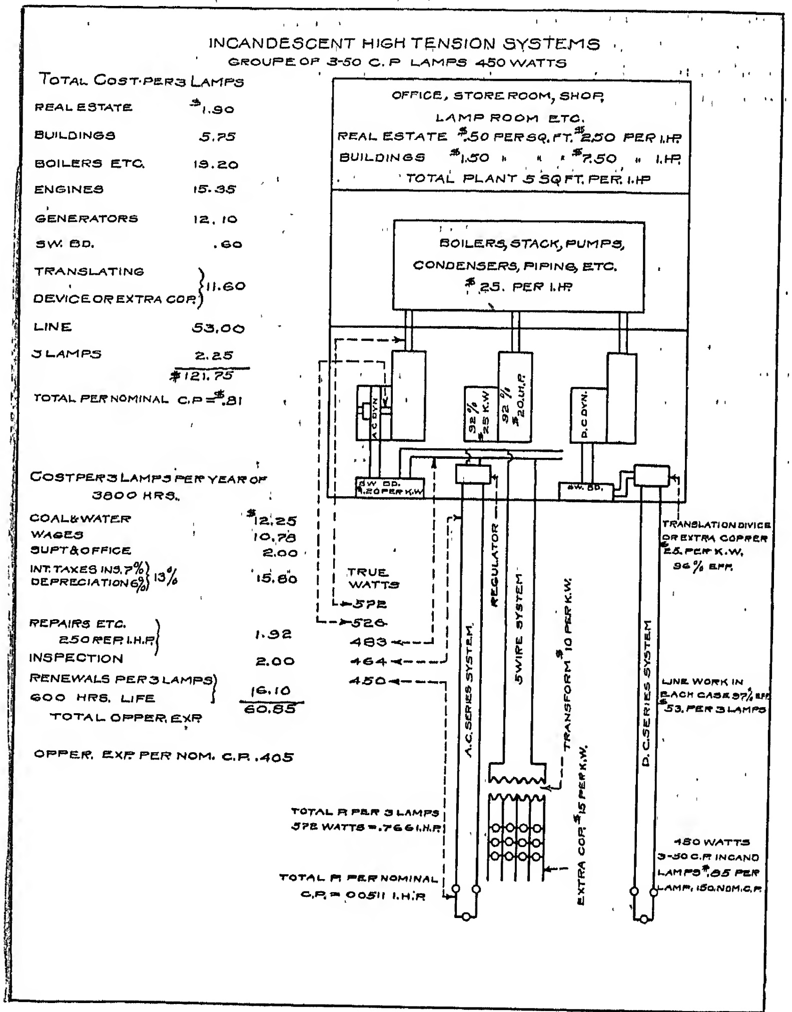


FIG. 13.

Another point in favor of the alternating systems is the fact that the location of the plant or other local conditions, may permit a saving in the line investment, for example, where a large number of circuits had to be run for a long distance in the same

TABLE A.

COST PER LAMP PER YEAR OF 3800 HOURS.	Hartford 400 watt enclosed.	Hartford 450 watt enclosed	Alt. C. Ind. Reg. 400 watt enclosed.	D C.Arc driven by A. C. motors 300 watt enclosed	D.C.Arc belted 300 watt enclosed.	D.C.Arc driven by D. C. Motors 300 watt enclosed.	D.C Arc belted 450 watt enclosed.	D.C. Arc belted 450 watt open arc.	D.C. Arc direct driven 450 watt open D C.	Alt. C. Ind. Reg. 450 watt enclosed. No incr. gen. plant.	D.C. Arc driven by A. C. motors 450 watt enclosed. No incr. gen. plant.	Rectifier System. 450 watt enclosed.	Incand 3-50 C. P. Lamps. 450 watts
	1	2	3	4	5	6	7	8	9	10	11	12	13
Total cost per lamp	146.50	155.24	139.80	131.42	117.90	129.45	147.37	142 60	142.00	91.14	100.40	154.30	121.75
Total cost per nominal c. p.	.154	.1349	.147	.146	.131	.144	.0982	.0713	.071	.0795	.0669	.103	.81
I H. P. per Lamp	.744	.822	.708	.630	.552	.642	.830	.832	.810	.804	.948	.816	.766
I. H. P. per Nominal c. p.	.000785	.000715	.000744	.000700	.000614	.000714	.000554	.000415	.000405	.000698	.000631	.000544	.00511
OPERATING EXPENSES.													
1. Coal and water	11.85	13.10	11.30	10.05	8.80	10.20	13.25	13.30	12.90	12.80	15.10	13 00	12.25
2. Wages	8.50	9.35	8.07	8.85	7.78	9.00	11.68	11.70	11.40	9 15	13.30	9.30	10.78
3. Supt. Office, etc.	2.00	2.00	2.00	2.00	2 00	2.00	2,00	2.00	2.00	2.00	2 00	2.00	2.00
4. Int Taxes, Ins, 7 per cent. Depreciation, 6 per cent. } 13 per cent.	19.00	20.20	18.15	17.10	15.30	16.80	19.10	18.50	18.50	11.90	13.20	20.00	15.80
5. Extra Deprec. Arc. Dyn.				.42	.49	.42	.68	73	.83		.63		
6. Extra Deprec. Arc Lamps	.80	.80	.76	.72	.72	.72	.72	.60	.72	.76	.72	.72	
7. Repairs, Renewals, Supplies	1.86	2.26	1.77	1.57	1.38	1 60	2.07	2.08	2.02	2.03	2.36	2.04	1.92
8. Extra Repairs Arc Dyn.				.32	.28	.32	.42	.42	.41		.47		
9. Extra Repairs, Const. C. Transf.	.15	.18										.48	
10. Trimming	5.20	5.86	5.20	2.60	2.60	2.60	3.15	DAILY. 11.00	ALT.DAYS 6.50	3.15	3.15	3.15	INSPECT'N 2.00
11. Carbons.	1.90	2.30	1.90	1.40	1.40	1.40	1.70	7.50	6.80	2.30	1.70	1.70	
12. Globes	1.60	1.80	1.60	1.00	1.00	1.00	1.30	.70	.50	1.80	1.30	1 30	RENEWAL 16.10
Total operating expenses	52.86	57.85	50.75	46.03	41.75	46.06	56.07	68.53	62.58	45.89	53.93	53 69	60.85
Operating expenses at 2000 c. p.	.0264	.0289	.0289	.0235	.02087	.0231	.0280	**.0342**	**.0313**	.0230	.0269		
" " rated at 1500 c. p.	.0353	.0385	.0338	.0306	.0278	.0307	**.0375**	.0457	.0417	.0306	**.0359**	**.0357**	
" " " 1200 c p.	.0441	.0482	.0423	.0375	.0348	.0386	.0467	.0572	.0521	.0382	.0418		
" " " 1150 c. p.	.0460	**.0503**	.0442	.0402	.0363	.0401	.0490	.0595	.0544	**.0399**	.0468		
" " " 950 c. p.	**.0557**	.0608	**.0535**	.0484	0440	.0484	.0591	.0720	.0656	.0484	.0568		
" " " 900 c p.	.0588	.0644	.0563	**.0512**	**0464**	**.0513**	.0624	.0760	.0695	.0559	.0599		
" " " 150 c. p.													**.405**

street, a saving in the investment could probably be made by the alternating system by the use of a sub-station at the point of distribution. The extra attendance and cost of the sub station would, in most cases, partially offset the advantage. Where the extra load would not interfere, the mains already in use might also be used for an alternating system.

In cases where there is already a greater generator capacity installed than is actually needed, it is, of course, possible to leave out a considerable portion of the investment shown in the tables. This would apply to any of the motor-driven direct-current systems as well as the A. C. systems. See Figures 10 and 11.

In rare cases, the peak of the commercial lighting and power load would not overlap the arc lighting load, and under such circumstances, some of the transformer systems, either direct or alternating current would have a great advantage.

Explanation of Tables.

The plants shown in the tables are, of course, intended only as diagrammatic representations of the conditions, and not as actual arrangements best suited for the purpose.

The tables are on what might be considered a minimum basis, that is, there is no allowance made for reserve in buildings or real estate, nor is there any allowance for reserve in the generating plant beyond the fact that the engine and dynamo units have been so subdivided as to avoid a great percentage of shut-down in case of accident. The cost of line has been reduced, and in fact all other items in the different plans have been reduced to what might be considered a minimum for a first-class plant. The alternating plants shown, have a slight advantage in the freedom from shut-down over the engine driven, direct-current plants, although in the latter the engine unit is sub-divided and an extra allowance is made for this and for arranging one engine to carry the greater part of the load in the case of accident to the other unit. In the case of Fig. 9 where the Arnold system is suggested, the direct current plant is not open to this objection, and for that matter, any of the plants could be arranged in this way without very great increase in cost.

No plans showing the ordinary low-tension constant potential A. C. arc system, have been put in, as the economy is so poor when compared with the series systems except when the system approximates the conditions shown in Fig. 3.

Figure 13 is intended to give a rough idea of the operating expenses of several kinds of incandescent lighting systems.

The diagram on the left might represent a series incandescent system with an inductive regulator in the station, or, it could represent a constant current transformer system.

The diagram in the middle is intended to represent a constant potential system of distribution which in some cases would have

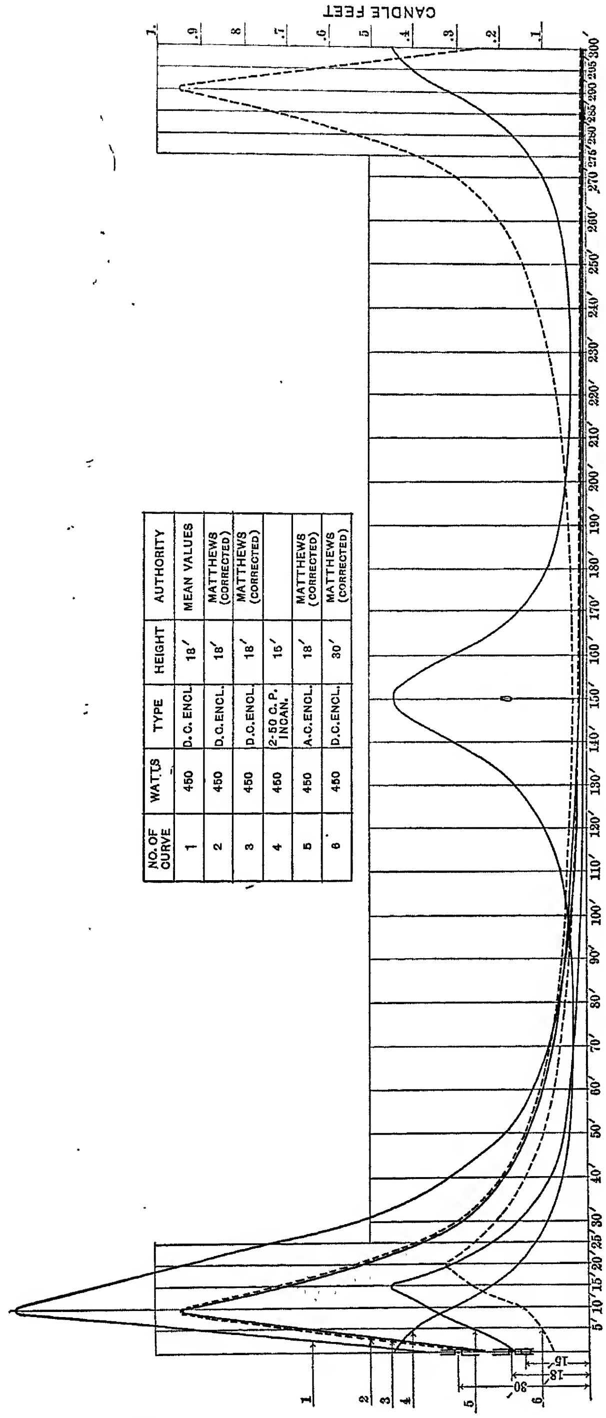
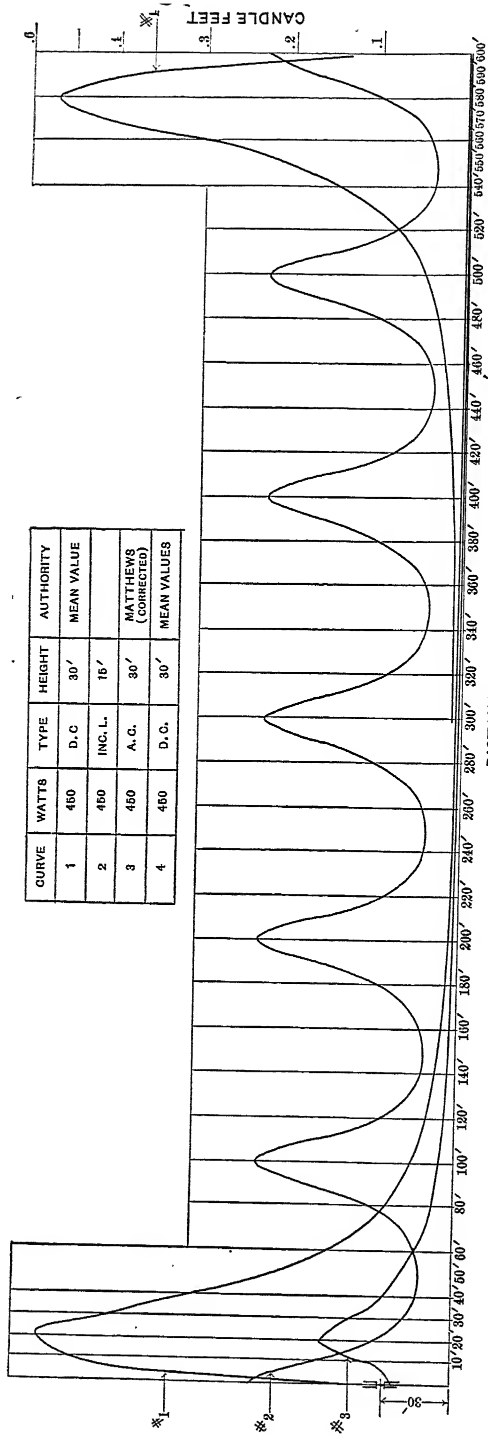


FIG. 14. Curves showing, Luminous Intensity at Street Surface with Different Lamps.



CURVE	WATTS	TYPE	HEIGHT	AUTHORITY
1	450	D.C	30′	MEAN VALUE
2	450	INC. L.	15′	
3	450	A.C.	30′	MATTHEWS (CORRECTED)
4	450	D.C.	30′	MEAN VALUES

FIG. 15. Curves showing Luminous Intensity at Street Surface with Different Lamps.

the advantage of utilizing some of the mains already in place for other work. The lamps are shown in series multiple but, of course, could just as well be in plain series or multiple arrangements.

The diagram on the right side might be taken to represent a number of direct current series systems. For example, a small dynamotor might be used where it was desired to run at a higher voltage than that of the station, and where no great amount of regulation was required. If considerable regulation was needed a double field motor generator might be used, the potential being regulated by the secondary machine. Machines like constant current arc machines could be used for this purpose. They could of course, be given much higher efficiency than arc machines, as they do not have to give the stability to the current which is necessary for running constant current arc lamps. This could even be extended to quite large machines of the multi-circuit type if there was any great amount of such lighting to be done.

Value of Items in Tables.

Real estate has been taken at 50 cents per square foot as representing a fair average value, the actual values ranging anywhere from nothing to seven or eight dollars per square foot.

Buildings have been taken at one dollar and a half per square foot, the range in this respect being nearly as great as for real estate.

Boilers, foundations, stacks, pumps, condensers, piping and other accessories have been lumped together at $25 per indicated H. P. We have figures on plants where this item runs as low as nine dollars and as high as $40 per I. H. P. of engine. This item has been increased to $27 per I. H. P. in the engine-driven D. C. arc plants to allow for extra accessories on account of subdividing the units. The engine and boiler items are, of course, inter-dependent as, when engines are cheap, the tendency is for an increased cost of the boiler plant. The attempt has been made to get an average current market value for all classes of boilers and engines.

Engines and foundations have been figured at $20 per I. H. P. This figure will run as low as $10. per I. H. P. and as high as $50 per I. H. P. for high-class triple expansion verticals. The rate has been increased to $22. per I. H. P. on some of the engine-driven plants, to allow for greater subdivision, etc.

A. C. generators and foundations have been taken at $25 per K. W. as a fair value of what would be put in a modern plant. These figures vary from $12. to $35. per K. W.

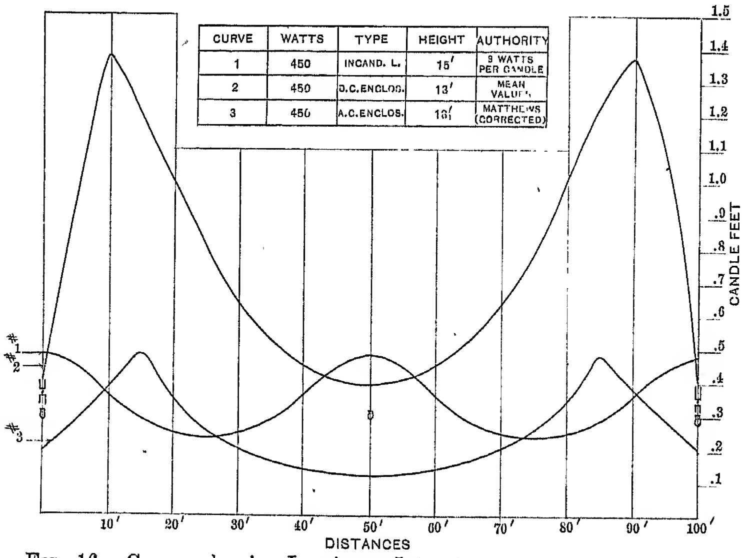
D. C. arc generators vary in price from less than $30 to $45 per K. W.

The belted arc machines have been taken at $35 per K. W. and the higher speed motor-driven machines at $33 per K. W. Large direct-driven machines would average about $45.

A. C. constant current transformers have been taken at $15. per lamp for both 400 and 450-watt lamps as there is considerable variation in the accessories to these transformers.

A. C. inductive regulators have been taken at $9.00 per lamp. This can be made a very variable item on account of the amount of regulation to be provided for as well as other reasons. The figure is intended to cover a regulator to control the entire circuit.

The line has been figured at $51.10 per lamp for the 300-watt enclosed D. C. lamp. This figure was based on the use of hard-drawn copper wire with weather-proof covering and the ordinary pole and suspension construction such as would be used in small towns or the outlying districts of cities. The size of wire for the other systems has been increased as nearly as possible in the ratio of the current, the other conditions remaining the same.



CURVE	WATTS	TYPE	HEIGHT	AUTHORITY
1	450	INCAND. L.	15′	9 WATTS PER CANDLE
2	450	D.C.ENCLOS.	13′	MEAN VALUES
3	450	A.C.ENCLOS.	13′	MATTHEWS (CORRECTED)

FIG. 16. Curves showing Luminous Intensity at Street Surface with Different Lamps.

It will be noted that an increase in the cost of this line construction will add a fixed amount to the investment and operating expenses, and will not affect the absolute differences between the systems. The percentage difference will vary, however.

The line and pole work such as is used in large cities will run from $100 to $150 per lamp, while underground cables and conduits will run from $200 to $300 per lamp.

The other smaller items will be found on the plans.

In the rectifier system shown in Fig. 12, the values of the items have been taken from corresponding parts of the other

tables and the rectifying commutator has been put in at $2.00 per K. W. in the absence of definite figures on the subject. It might be mentioned here that there seems no immediate prospect of commercial rectifiers of good-sized units except on very low frequencies.

The incandescent systems shown in Fig. 13 have been put in to afford a rough comparison with the arc systems. The corresponding items have been placed at the same values as in the arc tables. The lamps have been assumed to be 50-c p. lamps at an average cost of 85 cents per lamp, and having an efficiency of 3 watts per candle and an average life of 600 hours. It seems probable that these figures could be improved upon if such systems came into very general use.

OPERATING EXPENSES.

Coal and water have been figured at .42 of a cent per I. H. P. hour. This figure was obtained by averaging the average values given by Foster and Moses in their papers before the INSTITUTE, the values given in the *Street Railway Journal* and from a number of arc lighting plants on which we had figures. The values vary from .28 of a cent per I. H. P. to :76. .42 of a cent per I. H. P. hour corresponds with .7 of a cent per K. W. hour with 80 per cent combined efficiency for engine and dynamo.

Wages have been figured at .15 of a cent per I. H. P. hour in the boiler room; the same in an alternating current dynamo and engine room, and at .22 of a cent in the arc dynamo room.

The superintendence and office expenses have been figured at $2.00 per year per lamp in all cases, as this will not vary materially with the kind of plant used.

Interest, taxes and insurance are figured at 7%; depreciation at 6%; this depreciation factor might more strictly be called replacement, as it is intended to include not only real depreciation, but also a factor for replacing machinery caused by competition with improvements.

A sum at compound interest at 6% would equal the original in eleven and one-half years, so that this would seem to be large enough.

Extra depreciation on arc dynamos and arc lamps has been placed at 4%. This makes a total of 10% for the replacement factor on these portions of the plant. This would cover complete replacement in a little over seven years.

The general repairs, renewals and supplies have been taken at .07 of a cent per I. H. P. hour. Extra repairs on arc dynamos have been taken at .015 per I. H. P. hour. It might be remarked that in several modern arc plants, of which the figures are at hand, this value is considerably less.

Extra repairs on A. C. constant current transformers has been placed at .007.

The figures for trimming arc lamps have been taken from the data of the plants at hand. In all cases we have figures a little more or less than half the values used. In some cases the cost for trimming runs up nearly double the values taken. For example, we have figures varying from $1.00 to $6.25 per lamp per year for direct current enclosed lamps of 400 to 450 watts. The difference comes mainly in the time spent in cleaning the inner globes and in the price of labor as well as the number of lamps taken care of by a man. The figures on enclosed lamps are such as would allow the globes to be kept fairly clean, and the cost of trimming alternating enclosed lamps has been increased by a small factor on account of the practice which obtains in some stations of cleaning the globes of these lamps oftener than the direct current lamps under the same conditions.

The alternating lamps consume their carbons faster than direct current lamps partly on account of the increased wattage and partly on account of the almost universal practice of using one cored carbon. The use of the cored carbon also materially increases the blackening of the globe. In Figure 10 the 450-watt alternating lamp is assumed to have solid carbons, and has the same cost for trimming as the D. C. 450-watt lamp.

The cost for globes was taken in the same way as the trimming cost.

The life of incandescent lamps has been taken at 600 hours and the cost of the lamps at 85 cents. An allowance of $2.00 a year per each three lamps has been made for inspection and cleaning.

Curves of Illumination.

The illuminating values of different lamps depend quite as much on their location as upon the system of operation.

A number of curves have been plotted to show the illumination of the various types of lamps under different conditions.

The ordinates of the curves represent the illumination at various distances from the foot of the lamp-post.

It has been thought that for street lighting purposes, it was fairer to take as illuminating values the illumination on a plane normal to the ray of light in each case, rather than the values sometimes used which represent the illumination on the plane of the street and are the normal values multiplied by the sine of the angle between the ray of light and the horizontal. If the sine values had been used the results would, of course, have been much lower in value and the high lamps and the lamps nearer together would have a still greater advantage than what the curves show. It is probable that the useful effect is somewhere between the normal and sine values but nearer the normal.

In all cases no reflectors have been used, and no allowance has been made for the upper hemisphere of light. There is no doubt but that the light in the upper hemisphere is of considerable value, even without the use of reflectors, as the illumination

of surrounding buildings and trees saves a considerable percentage of the upper hemisphere of light, especially in wet weather. It will be noted in this connection that the incandescent and alternating arc lamps would both be quite materially improved if some allowance could be made for the upper hemisphere.

Figure 14 is a comparison of different arc lamps hung 300 feet apart and incandescent lamps 150 feet apart.

Curve 1 represents the illumination from a direct current enclosed arc of 450 watts.

The candle-power curve for this lamp was obtained by averaging the curves given by the following experimenters:

Matthews, Thompson and Hilbish, INSTITUTE Paper Opalescent inner globe....	384 watts at arc.
Freedman, Burroughs and Rapaport, INSTITUTE Paper. Opalescent inner, no outer globe....	410 " " "
Marks, Chicago Electrical Congress. Thin opal inner and clear outer globe	504 " " "

In each case the curves were increased or diminished in the ratio of the watts to reduce them to 450. The illumination would, of course, not vary in direct ratio with the watts, but it was thought that the error introduced in this way would be small compared with the great discrepancies introduced by other factors.

Curves showing the variation of the efficiency with different values of arc wattage appear to have maximum values depending on a great many conditions, and it was not thought worth while to attempt to assume any factors for correcting the curves other than in the direct ratio of the wattage. It is lamentable that there have not been more curves published, giving full information, and that we have to fall back on such methods as the above if we do not care to work from the results of individual experiment.

Curve 1 shows the light from one such average lamp hung 18 feet high.

Curve 2 is plotted from the results of Matthews *et al* used in making the above average. This was used as more information was given with the curve. Lamp hung 18 feet above street.

Curve 3 is the same as Curve 2 except that the illumination from two lamps 300 feet apart is considered, the result being the summation of two curves like Curve 2.

Curve 4 represents the illumination from six 50 c.p. incandescent lamps in clusters of two, on posts 150 feet apart, 15 feet above the street. The illumination from these lamps was assumed to be a hemisphere of 100 c. p. in radius. No reflector was used, and no allowance made for upper hemisphere. At three watts per candle these six lamps would consume 900 watts, which is the same power as given to the two arc lamps.

Curve 5 is for an alternating enclosed lamp with opalescent inner globe, taking 327 watts at the arc, as given by Matthews *et al.* No

reflector was used. The candle power distribution curve of the lamp was corrected in the ratio of 450 to 327 watts. It is regretable that no better curve for the alternating lamp was at hand for the purpose, as it undoubtedly does not show the alternating lamp to full advantage.

It will be noted that in the discussion of Mr. Matthews' paper, Mr. Marks thought that the D. C. lamp would be less than 35% better in efficiency than the A. C. lamp taken, whereas the paper gives more than 50% better efficiency for the D. C. lamp. Mr. Matthews, in a recent letter, has also stated that he thought this value should be reduced to something less than 35% so that it is fair to assume that the illumination curve from the A. C. lamp should be raised about 20% through all the curves.

Curve 6 is the same as Curve 2 except that the lamp has been raised from 18 to 30 feet high. It will be noticed that the street illumination is less near the lamp, but begins to be greater at distances over 140 feet. At 300 feet the high lamp gives about one-third more illumination. The mean ordinates come out as follows:

2-D. C.	encl.	18 ft. high,	300 ft. apart,	mean results,	....	.34
"	"	"	"	Matthew *et al.*	....	.18
"	"	30 ft.	"	"	....	.059
2-A. C.	"	18 ft.	"	"	....	.051

6-50 c. p. incandescent, bunches of 2, 150 ft. apart, 15 ft. high, .14

It will be noted that the mean illumination from the incandescent lamps is considerably higher than any but the direct low hung lamps. The minimum ordinate of Curve 3 is .034, that of Curve 4 is also .034.

Figure 15. The curves on this plate show the relative illuminations with a 600-foot distance for the arc lamps.

Curve 1 is the D. C. enclosed lamp from mean results as in Curve 1 of Fig. 14. The lamps are placed 30 feet high.

Curve 2 represents the illumination from seven 50-c. p. incandescent lamps 100 feet apart, 15 feet high. 2.6 watts[1] per candle.

Curve 3 is for the alternating lamp as in Curve 5, Fig. 14, except that it is hung 30 ft. high.

Curve 4 is the illumination from two of the lamps of Curve 1, 600 feet apart.

The value of the mean ordinate for the two D. C. enclosed lamps is .10 The mean ordinate for two alternating lamps would be .036. The mean ordinate for the incandescent lamps is .11 The minimum ordinate of Curve 2 is .037, that of Curve 4 is .007.

It will be seen that the relative effectiveness of the incandescent lamps increases quite materially with the distance be-

1. This efficiency could be obtained easily by the use of reflectors, or we might even hope to reach this result with the lamps themselves, if there were very large demands for such systems.

tween arc lamps, and that at greater distances between arc lamps the incandescent system would give a much better mean illumination.

Figure 16. This is a comparison of the lighting at short distances such as would occur in the business district of a city.

Curve 1 is the illumination from six 50-c. p. incandescent lamps, taking a total of 900 watts located in clusters of two, 50 feet apart. Height above street, 15 feet.

Curve 2 gives the illumination from two of the mean D. C. enclosed lamps taken for Curves 1 in the other plates. The lamps are 100 feet apart and 18 feet high.

Curve 3 is for two A. C. enclosed lamps as in the other plates, 18 feet high.

The mean ordinates are .35 for the incandescent lamps, .76 for the D. C. enclosed lamps and .28 for the A. C. enclosed lamps. The relatively poor showing of the A. C. lamps in this case is partly due to the low efficiency of the lamp as discussed previously, and partially to the fact that its light is more concentrated near the horizontal plane. Reflectors on the lamps and reflection from buildings would bring up the utility of the A. C. lamp considerably.

CONCLUSION.

A perusal of Table A, which gives a summary of the different systems, makes it evident that open D. C. arc lamps show up quite well as compared with more recent improvements when only the quantity of light is taken into consideration. It must be borne in mind that to get these results for open arcs the most modern apparatus has been taken in the station, and the operating expenses are also reduced to the best average modern practice. It is perhaps not fair to compare the open and enclosed lamps without any consideration of the quality of the light, so that we will have to discount the results for open arc lamps, depending a great deal upon individual opinion.

The alternating arcs do not show very favorably in making the various comparisons. The principal loss comes from the relative inefficiency of the arc itself. If this can be improved upon, or if the ratio taken between the D. C. and A. C. arc can be brought down, the relative economy of the A. C. systems would increase quite rapidly.

In general it will be seen that the D. C. plants are the most favorable for places where the whole or nearly all the output is used for arc lighting. Where but a small portion of the load is arc lighting, either the straight alternating systems or some of the systems transforming into direct continuous current by means of motor generators or rectifiers would be the most practicable.

There seems to be no particular reason why large direct current lighting or railway plants should not go into the series arc lighting business more than has been the practice. It appears

that they could operate arc lights or direct current series incandescents with very good economy as far as the lighting is concerned, and probably increase the economy of operation of the rest of the plant as well. Where there are already storage batteries installed, there are a number of additional advantages resulting from the combination. In this connection it might be well to note that the ordinary direct current arc machine is perhaps the best suited of all generators to be driven at variable speed, so that there is not likely to be any great disturbance on the arc circuits caused by a fluctuation of speed or voltage in a railway plant.

The problem of building motors to run at a fairly constant speed with reasonable variations in voltage has also been taken up recently and solved with fair success.

The curves of illumination seem to show that arc lighting is by far the most economical method of lighting the central parts of cities, while in sparsely populated districts incandescent lamps seem to have a great many advantages. There is no doubt but that the very glare of an arc lamp impresses the public considerably, and that in passing from open arcs to enclosed and then to incandescents we are losing this effect and tending in the direction of Welsbach or ordinary gas lighting.

AMERICAN INSTITUTE OF ELECTRICAL ENGINEERS.

NEW YORK, December 27, 1899.

The 138th Meeting of the INSTITUTE was held this date at 12 West 31st Street and was called to order by President Kennelly, at 8.15 P. M.

The Secretary announced that at the meeting of the Executive Committee in the afternoon, the following associate members were elected:

HARDY, CARL EARNEST,	Student, Cornell University, residence, 306 Huestis St., Ithaca, N. Y.	L. S. Randolph. Fred'k Bedell. Harris J. Ryan.
JAQUAYS, HOMER M.	Lecturer in Mechanical Engineering, McGill University, residence, 862 Sherbrooke St., Montreal, Quebec.	R. B. Owens. L. A. Herdt. C. H. Davis.
MISAKI, SEIZO,	Chief Engineer and Superintendent, Hanshin Elec. R. R. Co., Front Sannomiyo Station, Kobe, Japan.	W. E. Goldsborough Harold B. Smith. K. Iwadare.
MOODY, VIRGINIUS DANIEL,	Senior Student, Cornell University, residence. 215 Dryden Road, Ithaca, N. Y.	Edw. L. Nichols. Fred'k Bedell. Harris J. Ryan.
TAYLOR, JEREMY F.	Electrician, Detroit Copper Company, Morenci, Arizona.	C. F. Bancroft. Ernst Berg. W. C. Woodward.
WOLFF, FRANK A., JR.	Professor of Physics and Electrical Engineering, Corcoran Scientific School, Columbian University and in office, U. S. Standard Weights and Measures, Washington, D. C.	W. D Weaver. J. E. Woodbridge. T. C. Martin.

Total 6.

The following associate members were transferred to membership:

HEWLETT, ERNEST HOLCOMBE	Electrical Engineer in Chief Control, Rockhampton Gas and Coke Co. Ltd.; residence, Estoril, Rockhampton, Queensland, Australia.
KNOX, CHAS. EDWIN	With C. O. Mailloux, Consulting Electrical Engineer, 150 Nassau St., New York.
BURTON, WM. CORWIN	With J. G. White & Co., 29 Broadway, New York City.

THE PRESIDENT:—The first business before the INSTITUTE this evening is a paper upon the "Cost of Arc Lighting," copies of which you have before you. This is a communication in discussion of Prof. Robb's paper that was read here on September 27th. Mr. Wait is unfortunately not here this evening, but Mr. Albright has kindly consented to read the communication in his absence.

[See p. 555.]

THE PRESIDENT:—Accompanying this paper are sixteen diagrams and also a summary, to which the whole paper appears to tend, appearing under thirteen columns. The paper is now before you for discussion.

DISCUSSION IN NEW YORK.

MR. C. O. MAILLOUX:—I regret very much that I am not able to contribute to the discussion, because I have only just seen the paper and the diagrams. I am greatly impressed with the evident care and thoroughness bestowed upon it. The paper seems very valuable and it evidently contains a great deal of useful information in convenient and complete form. I regret very much that I have not had time to study it so as to be able to discuss it intelligently. The paper is not perhaps one that admits of, or needs much discussion. The paper is really a statement furnishing comparative data very useful for reference which the members of the INSTITUTE can have before them whenever they wish to investigate matters of this kind.

It affords perhaps a more complete presentation than any yet attempted of the points of difference and of the items of relative cost which should be considered in making a comparison between various methods of operating arc lamps.

Wait on Cost of Arc Lighting.

[See p. 555.]

Discussion in Chicago, December 27, 1899.

Mr. F. N. Boyer:—I had hoped to come prepared this evening with some figures based on the actual operation of the Hartford system in a number of stations in which it has been installed throughout the country. It was only a few days ago that my attention was called to the very interesting paper read by Mr. Wait this evening, and, owing to the holidays intervening, and some rather pressing business, I was unable to get what I wanted; and, therefore, rather than discuss the figures which are given by Mr. Wait, I will refer briefly to what has been done in the installation of the system.

Something over a year and a half ago the first installation was made at Hartford, Conn. Since that time something over 6,000-light capacity has been installed in other cities. In nearly every instance the installation was not made until after the Hartford system had been inspected, either by the prospective purchasers or by engineers appointed by them. Of course, in the first place, the only place to inspect it was at Hartford. Since then so many installations have been made in various parts of the country, that it was not necessary to go to Hartford; plants could be seen nearer home.

A notable instance of the installation of this system is at Omaha, with 400 lights used for street lighting, where the direct-current open type has been replaced by the same number of the alternating-current, enclosed series, 6.6-ampere lamps.

In St. Louis, where, as you all know, the Missouri-Edison company has been practically operating the Hartford system, but instead of having an automatic regulating transformer, it has been using a transformer with fixed coils and a hand regulator, using the open arcs instead of the enclosed arcs. When the Missouri-Edison company installed its underground three-wire system-instead of putting in the open arcs, it put in enclosed arcs, using, however, a multiple arc, instead of a series arc. The reason for this was that the company wanted to connect the lamps to its system of three-wire mains. The St. Louis people and the Omaha people both have large installations, and they, as well as the owners of a 100-light installation at Adrian, Mich., report very favorably. The general public, the people whom the lamp owners are trying to please, are as well satisfied as they were with the old system, and, in some cases, better.

It has been clearly established, of course, from a commercial point of view, that the enclosed arc lamp is a success for street lighting. As to its economy in operation, we don't claim that for a station operating street lighting alone—that is not doing any commercial lighting—the Hartford system is

the system to install. In that case, we believe that the direct-current, operating from a direct-current series machine, with enclosed arc lamp, is the system to install. For a local lighting company doing a commercial business as well as street lighting, there is no doubt at all that the Hartford system, used in connection with the alternating machine, is the proper system to install. Take Omaha, for instance. The company in that city some few years ago had a station, I think, of three stories, and each one of the stories was filled with operating machinery. Now there is a one-story building, since the installation of the Hartford system, and the company has scarcely filled the first floor, using the alternating current successfully, with large units, by which motors, arc lamps and incandescent lamps are supplied from the same source of power. That is where we claim that the alternating series system is economical.

I am sorry that the time was so short that we could not present to you some figures showing the actual operations of the Hartford system. At some future time I will, perhaps, be able to give you those figures, because the system has been watched very closely, both by the managers of the companies that have installed the system and by our own engineers, and we are now just about prepared to give figures based on actual operations.

Mr. George A. Damon:—Our office recently adopted a system of street lighting, for a suburban town, which allows a combination of one circuit of series alternating-current arc lamps controlled by an inductive regulator, and two or three circuits of series incandescent lamps, both arc and incandescent lamps being run from one alternating-current machine.

Considering the best system to be adopted for these small towns, there are a number of things to take into consideration. The question of relative efficiency and total cost of installation and operation of arc-lighting systems has been very thoroughly covered in Mr. Wait's paper, but these items of cost and efficiency are not always the governing considerations—especially in plants of moderate size. In such a case it is desirable to locate arc lamps in the center of the city, but in the outlying districts, where the population is scattered, incandescent lamps are satisfactory. As has been pointed out, the mean illumination from incandescent lamps may be higher than that obtained from the same amount of energy used in arc lamps, but, on the other hand, there is no doubt but that a town lighted by arcs appears to be the better lighted. Most city councils like to have their towns look, from the railroad at least, as if they were well lighted, and the advantages of arc lighting for this purpose generally appeal to them. In the installation already referred to, there was considerable commercial incandescent lighting to be taken care of, besides the arc and incandescent street lighting, so that the best system was thought to be an alternating-current dynamo, capable of handling all classes of service, and the only question considered

was the relative advantages of the two or three commercial systems which would accomplish this result.

I notice that Mr. Wait, in his discussion, has reduced all values, for the purpose of comparison to the cost per candle-power. This compares the quantity of light given off by an arc without taking into account the quality. Now, it has been often pointed out that there is considerable difference between the candle-power of an arc lamp and its illuminating power. Furthermore, the candle-power of an arc lamp is a hard thing to measure with any given lamp. When it comes to a comparison between all the different kinds of arc lamps—open arcs, enclosed arcs both alternating and direct current—there is considerable variation in the reported results, and any deductions of relative cost based upon these figures will necessarily be as unsatisfactory as are these reported results themselves at the present time.

You will notice that Mr. Wait uses the ordinary rating of 2,000 candle-power for the open series-arc lamp. This rating has always been unsatisfactory, and it is unfortunate that we don't make some effort to get away from it. Allowing 2,000 candle-power for a 450-watt lamp, there will be only 0.225 watt per candle-power, whereas, in the values quoted from Professor Thomson and L. B. Marks, the watts per mean spherical candle-power for open arcs are given at 1.2 and 0.95, which indicates that these authorities are using candle-power ratings of about one-fifth the 2,000 candle-power value usually taken. Fortunately, however, the ratio between the costs as given, and also the conclusions drawn would not change, even if the candle-power basis were to be taken at nearer its true value.

In the final table, showing the conclusions to be drawn from Mr. Wait's calculations, I was interested in noticing, in the comparison of the operating expenses per candle-power, that the cost is less (the value being 0.0313) for the station using the 450-watt series-arc lamp operated from direct-connected arc dynamos. This brings us back to the opening sentence of Mr. Wait's paper, in which he states that the figures were originally made to see whether or not it would pay to build a direct-current arc machine suitable for direct connection. I would say that his conclusion might be that it would pay, although he has not said so, and I should like to hear his conclusion on that subject. It strikes me that the great want at the present time in power-station work is a direct-connected arc dynamo—a machine we can install in our stations on the same basis as the large alternators; that is, a machine that can be built in large sizes and directly connected to a Corliss engine without a countershaft.

Such a plant is shown[1] by Fig. 9, and if I read Mr. Wait's figures aright, this arrangement shows the best results from an operating standpoint. The diagram shown in Fig. 9 provides for a direct-

1. *Western Electrician*, January 13, 1900, page 25.

connected arc plant, and also for other units to be used for other purposes. Owing to the fact that the arc-lighting load and the commercial incandescent and power load will overlap under ordinary circumstances, it will usually be found desirable to have separate dynamos for the arc-lighting circuits, and the arrangement suggested indicates a desirable one for many stations. For instance, the center engine could be a center-crank engine, directly connected to two large arc dynamos. The unmarked units at each side could be alternating-current, or even direct-current generators for commercial work, directly connected to side-crank engines. It is hardly necessary for me to point out that this arrangement would be much more satisfactory and reliable if all the engines and generators were interconnected by means of the Arnold system, so that the crippling of any one engine unit would not interfere with the output of the plant. One of the most interesting points brought out by the paper is whether or not we are tending toward a large direct-driven arc machine.

MR. ALEXANDER CHURCHWARD:—I should like to ask Mr. Boyer one question in regard to the power factor of that system (if he were here), because I think, from what I understand of the constant current system of the General Electric Company, that you get a comparatively low power factor, and if very low, of course, it will upset the regulation of your machine. I understand that the power factor is from 60 to 70 per cent. under full load. Now, if you have a power factor of 70 per cent., a much larger generator will be needed to supply a given number of lamps than if the arc machine were driven by a direct-current or synchronous alternating-current motor. Our losses with the low-power factor would increase and cut down the efficiency of the generator, and our operating expense certainly would go up, and also the cost per lamp; because with the low-power factor we need a larger machine than with a high-power factor. That would increase the cost of the alternating lamp per candle-power and spoil the regulation of the system. Therefore, if we are going to spoil the regulation by putting on a series-alternating lamp, that again will be a loss. For instance, if you take a small plant of 200 kilowatts and put on lamps equal to 50 kilowatts with 70 per cent. power factor, that is going to interfere with the regulation of the rest of the load.

MR. FOSTER:—We do it at better than 70 per cent.

MR. CHURCHWARD:—If it is any better than that let us know what it is.

MR. WARNER:—I can answer that. I was assured by Mr. Sunny the other day that the system gives a power factor of a little over 80 per cent. under full load.

MR. CHURCHWARD:—What would it be under three-quarters load?

MR. WARNER:—I didn't get that.

MR. CHURCHWARD:—Taking any of our existing stations to-day, where we want to run arc lamps, if the machine is composite wound and the voltage rises 10 per cent. under full load, with a 95 per cent. power factor, if the power factor is reduced down to from 80 to 75 per cent., we lose our regulation. If we are going to lose our regulation by using that system, I don't think we would gain much by putting in a synchronous motor and driving the arc machine. So that the power factor being better, we would then get better results and better efficiency, and the cost per lamp would be brought down, as shown by the diagrams; we would not upset the regulation of our station, and I think this is one of the main points. It is poor enough now. I don't think it advisable to put in a system that is going to reduce the regulation 10 or 15 per cent. unless we have a man to watch it all the time, which means an additional expense.

MR. E. P. WARNER.—I am sorry to say I have been so busy lately that I have had little time to prepare myself for the discussion of this subject this evening. I have had occasion to look over a number of statements that have been made regarding the power factor of the various alternating systems of arc lighting, and among them, of course, the Hartford system. I have noticed by some advertisements that the power factor was as low as 70 per cent. at full load. I asked people who knew what it was, and was assured that it was about 80 per cent. I feel just as Mr. Churchward does, in regard to the matter of the effect on generators. Unless we can get a series alternating system in which the power factor is certainly not less than 90 per cent. we can't be considered in a position to compete with the direct-current, enclosed-arc system.

Coming to the tables that Mr. Wait has prepared, they show very thoroughly and fully some very interesting points regarding the comparative cost of operating plants. I don't find anything there, however, that would approximate the conditions of a plant such as Mr. Boyer has called attention to. That is, one in which a large amount of the business was "commercial" lighting, using ordinary incandescent lighting, either commercially or on the street, and in which only a very small proportion of the business is arc lighting.

I should be very much interested, if there is anyone present who can give it, to have information as to the real economy that can be obtained by the use of the Hartford system, or some system akin to that, in, say, an alternating station that has been already established, where they are doing constant-potential arc lighting and incandescent lighting, and power work.

MR. R. H. PIERCE:—I would like to call on Mr. Wait again in regard to this matter brought up by Mr. Damon; that is to say, as to his conclusion on the advisability of installing large direct-connected, direct-current units, and whether or not there

is a tendency in that direction. One thing is certain, that the economy which various companies are trying to get by these different systems, they aim to bring about by the use of large units, which, perhaps, in general, will increase the efficiency and decrease the labor account, which is a considerable item. And I suppose that any analysis would show that a large proportion of the decrease in expense in any system is due to the use of a few large units. Therefore, it is very pertinent, I think, for us to learn the status of the large connected direct-current machine.

MR. WAIT:—Taking up some of the points that have been mentioned in the discussion, I might first call attention to Mr. Boyer's remarks that the Hartford system has been installed in a very large number of plants, and that it has almost universally given satisfaction. This really comes back to the same point that is taken up at the very beginning of the paper—that the Hartford system, in practically all cases, I think, has displaced some of the older forms of open-arc systems. It is more than likely that in a great many of these cases a modern direct-current system could have displaced the older open-arc systems and have furnished better light to the public at a less cost to the station.

In this connection I have heard recently of a town near here, where they are operating both the alternating and the direct-current systems and the old direct-current company is making life miserable for the alternating company by poking the public up to perceive that the alternating lamps don't give out quite as much light as their lamps.

The alternating systems and the enclosed direct-current arc systems offer a very fine opportunity of putting up a confidence game on the public. That is to say, it will quite frequently be possible to convince city councils or other uninitiated persons that a lamp taking less watts will give more satisfaction for street lighting than some of the old open lamps. That this is possible will readily be seen from a comparison of the candle-power curves of open and enclosed lamps, either direct or alternating. The enclosed lamps, especially the direct-current, give considerable more light near the horizontal than the open arc, so that actual photometric measurements, taken in the middle of a long block, from an open lamp at one end and an enclosed lamp at the other end, will show to the advantage of the enclosed lamp. The advantage of the enclosed lamp is, perhaps, even more apparent to the eye, because the effect of the comparatively diffused light from the enclosing globe seems to make a greater impression than the twinkling beam of the open arc. Quite frequently, the observer will think that the enclosed lamp is the brighter, judging by looking at the lamp, while, if he looks down at his shadow, he will see that the open lamp is making the darker shadow.

Another point that influences such tests, is the extreme varia-

tion in the light from an open arc; that is, if the carbons are arranged either by accident or design so that there is considerable shading of the crater, the light in the direction of observation may be quite small. The enclosed lamps, of course, are not subject to nearly so great variations in this respect, partially on account of the greater length of the arc, and partially on account of the superiority of the more recent mechanisms. For example, a 1,200-candle-power open arc, with carbons poorly adapted to the conditions, and having the ends overlapping, will give practically no light in certain directions.

The light on the sidewalk near the open lamp is, of course, much greater than from the enclosed lamps, but in a great many cases it is possible to convince purchasers that this very brilliancy is a disadvantage, because it makes the distant regions seem even darker, on account of the comparison. In addition to the other arguments in favor of the enclosed lamp, its superior steadiness and the greater reliability of the newer mechanisms make it find favor, both in the eyes of the public and the station man.

Most of us would probably be glad to see the old systems displaced by enclosed lamps, but it is only fair play to the open arcs to bring out some of these points and show that a great many of the evils can be cured by the use of modern mechanisms, carbons adapted to the conditions, and globes which will diffuse the light or distribute it in the direction desired. The city of Brooklyn might be cited as an example, where the authorities would not permit the substitution of alternating enclosed lamps for direct-current open lamps.

Mr. Boyer has referred to the cost of operation and other matters in connection with the Omaha Thomson-Houston company. I have a letter from Mr. White, of this plant, in which he gives an account of some photometric tests he made out in the street, in which he obtained more light from the alternating 450-watt arc than from his open direct-current 450-watt arc. The results of these observations are evidently what might be expected, and the difference between these results and those given by Mr. Steel in his communication is probably due to the angles of observation and other differences, a number of which have been previously mentioned.

Coming to the plant mentioned by Mr. Damon, I would like to ask how many arc lamps there were and what system was adopted?

Mr. Damon:—There were 17 lamps to be installed on the Manhattan system.

Mr. Wait:—It is evident that the small number of arc lamps is alone a sufficient reason for not considering direct-current arc machines, and that this fact also puts the Hartford system at a disadvantage commercially. This question of the ratio of the arc-lighting load to the rest of the plant is the all-important one in deciding between the direct-current and alternating arcs. It

will be seen that the reasons for deciding on alternating arcs in this plant will be maintained in considerably larger plants, where the arc load is still a very small portion of the total.

Mr. Damon and Mr. Pierce have both asked about the possibility of obtaining large arc machines. I might mention that our company (Western Electric Company) has sufficient confidence in the future of large direct-current arc machines to undertake the development of a line of multi-circuit machines. The larger sizes of these machines are not ready for the market as yet. There has also been some mention in recent periodicals of the development of large arc machines by other companies.

Mr. Churchward has asked about the power factor of the alternating system at light load. The power factor at three-fourths load in the Hartford plant was stated by Professor Robb to be 62 per cent and 24 per cent, at one-fourth load.

This question of power factor brings up a point in connection with the operation of the plant. Suppose, for example, we have an alternating plant in which the same generators and engines are to be used, both for the arc-lighting load and other purposes. If the engine has the same capacity as the generator, it will not run at an economical load when used on an arc load of low power factor, unless the generator is run at a considerable overload. It is for this reason that in the tables, the generating units for the arc load have been arranged in proportion to the power factors, so that the generator and engine would reach their economical limit at about the same time. If one of these units is used on a nearly non-inductive load, the generator will then be working at less than its maximum economy. Where all generators can be run in parallel and the arc lighting is a small part of the whole, a low power factor in the arc load will, of course, not have so much influence.

There has not been very much said about alternating inductive regulator systems. I am sorry there is nobody here to speak up for these systems, as they undoubtedly have a good many advantages that might be brought out. I have no figures on the actual results obtained in practice. In the published accounts of some of these systems, power factors as high as 90 per cent are claimed, and from the results of some tests that I have in mind, I think it is quite possible to obtain results very nearly as good as this, and even better in some cases. This very feature of a high power factor gives such a system a considerable advantage over other alternating systems. An unusually high efficiency is also claimed for some of the lamps used on these systems.

Mr. Warner has brought up the comparison of alternating and direct-current systems for "commercial" lighting. It is evident in general, that the alternating systems would have somewhat more advantage for this class of work than would be indicated in the tables. The motor-driven or rectifier systems, however, share these advantages with the straight alternating systems, and

the latter have the great disadvantage mentioned in the paper, of either not operating satisfactorily at all on light loads or having quite low power factors. Tables 10 and 11 are intended to be especially applicable to these conditions.

Mr. Pierce spoke of the increased economy of large generating units on account of less attendance, etc. I might mention here an arc plant in which there are ten 150-light machines and two engines, in which there are only two men in the engine room. There is also another plant in which there are 12 machines, a countershaft and three engines, in which there are only three attendants in the engine room. These plants are both three or four years old and have two well-known makes of arc machines. From a consideration of these plants it is difficult to see how there can be any great difference in the item of attendance between modern arc machinery and other larger generators. It is quite evident that there will be some difference, but the item is so small that it does not affect the total cost very materially.

Before I stop, I would like to emphasize the desirability of getting some relative nominal rating for the different kinds of arc lamps, otherwise both parties to a contract will have all sorts of difficulty in settling on a reasonable basis. It does not seem possible to adopt any actual candle-power ratings, without giving rise to endless controversy. The hopelessness of rating by actual candle power is emphasized by the suit now pending in a good-sized city, where all sorts of contentions are made concerning the light of a standard form of open-arc lamp. If there can be so much controversy over a single type of lamp, which has been in use for so many years, what may we expect when we have competition between all the various forms of lamps now on the market. I understand that some steps toward standardization have been taken by the National Electric Light Association. It would seem very desirable to discuss this matter as fully as possible, so that the association or some other representative body can get together all the information there is on the subject.

MR. F. L. MERRILL:—Being only a privileged guest, this evening, I have hesitated to say anything until invited. I can only say that our company has the Manhattan system, which includes the reactive regulator and the new-type concentric lamp, the lamps being without series coils and having only one magnet therein. We have a large amount of business that calls for the use of no transformers. This system permits the use of a series of about 25 or 26 lamps connected directly across 2,000-volt primaries, which are being installed all over the country. In case people want to use a higher number of lamps than 25, a step-up transformer is a very simple proposition. In a large installation, an alternating unit of the required voltage, operating nothing but arc lamps, may be used. An example of this is the Los Angeles and San Gabriel Electric company, at Los Angeles, Cal., having nine circuits of 100 lamps each. These will be oper-

ated from a 7,500-volt generator without transformers. We are installing at the Union Stock Yards, for Swift & Co., 150 lamps, which will burn in six circuits, two circuits on a transformer, and each transformer on one phase of a three-phase system. In this case we shall step up from 220 volts to 2,000.

Regarding lighting from alternating lamps, my own impression, from observation, is that the light is more satisfactory and more reliable for street lighting. The average grade of carbon that is used in open arcs is not very satisfactory, and much depends upon that as to the degree and amount of light. The open-arc, direct-current lamp is complicated and throws shadows directly under the lamp, and a decrease in efficiency is noticed in a very short time. The enclosed lamp, of course, is not affected by the wind. In the new type of lamps which we are putting out, the side rods are only about one eighth of an inch in diameter, and throw practically no shadow at all.

In my own observation, near my residence, there is a block lighted, by private subscription, from the mains of the Commonwealth Electric Company, and on the next street, a parallel boulevard block, that is of the same length, on which the high-tension system is in use. There are more lamps on the boulevard, all of the latest type, with opal globes, and I believe that the first block, with a smaller number of six-ampere alternating lamps, is better illuminated.

The Manhattan system has been put in in a great many places, replacing small plants of open arcs. The satisfaction is almost universal. The diffusion of the light from the globes of the enclosed arcs seems to me more satisfactory for general illumination.

I believe that the alternating system, compared with the old-style, direct-current arc system, which it will probably supplant, in a great many cases, is a very fair test of the efficiency of that system. It represents a dismantling and throwing out of almost obsolete types of machinery in a great many cases. It means the throwing out of old types of lamps that probably have not been kept in repair. The average distribution of light from a direct-current arc is not the best. Most of the six-ampere lamps are better than the direct-current lamps of ten amperes.

Putting in the alternating-series system, under ordinary circumstances, is to place it in the hands of inexperienced men. I think if the system will operate satisfactorily under those conditions, that it is a very fair test. There is no question about the efficiency of an alternating plant, with the series lamps under our system. We are prepared to guarantee a power factor of 89 per cent. at full load. As to partial loads, I cannot say; but I promise it will not run under the Hartford system. The loss in our regulator is constant, being simply the I^2R loss and a small iron loss. The loss in a 50-light regulator is only 150 watts. In fact, in a 50-light system the loss is equivalent to one lamp,

as against five lamps in the Hartford system. The regulator has only one coil, and can be replaced, in case of a burn-out, in 10 minutes. There is absolutely nothing else to get out of order. The company has sold and put in nearly 3,000 lamps in the last six months.

MR. WAIT:—I would like to ask Mr. Merrill about the San Gabriel plant that he has mentioned. There were nine circuits of 100 lamps, I believe, at 7,200 volts constant potential.

MR. MERRILL:—It is about 7,500.

MR. WAIT:—I would also like to ask what provision is made for taking care of a ground on the positive side of a circuit when there is one on the negative side of one of the other circuits. If the regulators were to take care of only a portion of the circuits, one would expect to see the whole system shut down, unless it was protected by other automatic devices besides the regulator.

MR. MERRILL:—I do not believe I am sufficiently familiar with that installation to reply exactly. It is, however, provided with regulators which can be made to take care of a large part of the capacity of the circuit. A ground coming on the opposite sides of any two circuits of the system will, so far as I can say offhand, cut out the number of lamps that the regulator would take care of in the portion grounded.

MR. WAIT:—It would seem that in order to get complete independence of a large number of circuits on such a system, it would be desirable to have static transformers in between the generators and the series system. That is the reason that wherever such systems are shown in the tables, an addition has been made for static transformers. Since making up these tables, it has occurred to me that it would not be necessary to have transformers for the entire capacity; but that a certain number of transformers might be provided to throw in where trouble occurred.

Mr. Merrill has also spoken of the direct-current lamps being somewhat complicated. I suppose that is a matter of opinion; but there is one thing certain, and that is that the alternating lamps are liable to produce a humming, even under the best conditions.

I think there is no doubt that an alternating-lamp mechanism is intrinsically a more difficult piece of apparatus to maintain than a direct-current mechanism of the same character. In actual practice it has been found quite difficult to maintain alternating lamps in service with anything like the amount of attention given to direct-current lamps. It is only fair to the alternating lamps to state that there has been quite a rapid improvement in the lamps that have appeared recently.

Another point to which Mr. Damon has called attention is the intermittent effect of the light on moving objects, from an alternating arc of low frequency; that is, a moving object will be seen as a series of impressions, instead of in the ordinary way. This might be somewhat annoying, under certain circumstances.

I understand that the light from an incandescent lamp run from a very low frequency current sometimes becomes quite painful to the eyes, even though the person does not realize the fact that the light is varying. It is my impression that where such cases have occurred, the trouble has been overcome by using a low-efficiency lamp. One would expect that the same effect would occur to a more marked degree from the lower frequency alternating lamps, if these were situated where they were used for work requiring close application.

Mr. Merrill spoke of the power factor of the inductive regulator system as 89 per cent. I would like to ask the size of regulator with which this figure corresponds, that is, if it is a 100 per cent. regulator, what will be the power factor of a circuit with a 10 per cent. regulator.

Mr. Merrill:—We manufacture a number of sizes of regulators adapted to different uses. For instance, a 100 per cent. regulator for 25 lamps would be a 50 per cent. regulator for 50 lamps, and so on in that proportion. The loss in the regulator being constant at all loads, we can maintain that power factor. In actual tests, we have obtained 91 per cent.

Mr. Wait:—It would appear, then, that the size of the regulator has some influence on the power factor?

Mr. Merrill:—That is, the capacity of the regulator.

Mr. Wait:—Yes, that is, the per cent. of the circuit it can take care of.

Mr. Merrill:—Our statement is based on one hundred per cent.

Mr. Wait:—Another statement made was that the loss in the regulator was constant. We would naturally suppose that the hysteresis loss might vary somewhat with different loads.

Mr. Merrill:—I believe I made the statement it was an I^2R loss with a small iron loss.

Mr. Wait:—Which, of course, would vary a little.

Mr. Merrill:—Yes.

Mr. Wait:—Do you know how much that iron loss is?

Mr. Merrill:—I do not.

Mr. George B. Foster:—Mr. Wait, did I understand you to say that you had figured the price of transformers in your proposition number ten?

Mr. Wait:—Yes, the transformers are figured in that; also in this one here (indicating.) This is practically the same thing as the Manhattan system.

Mr. Foster:—I do not see why a transformer in that system would be necessary, as you already have the voltage required on the primaries. Regarding short-circuit on the line, suggested by Mr. Wait, this will be taken care of by the regulator, which would quickly choke the circuit, preventing any more serious damage than occurs on the direct system, when operated by an automatic series dynamo.

MR. WAIT:—I think that in actual practice, where there is a considerable amount of alternating series lighting in conjunction with a constant-potential alternating system, it will be found desirable to separate the series system by static transformers or some other method, on account of the quite frequent occurrence of grounds of both high and low resistance on series arc circuits. These grounds, while they may or may not shut down parts of the system, would be a source of considerable annoyance, and even danger, to other parts of the system. As mentioned in the description of the tables, the static transformers were put in partially on this account and partially from the fact that, as a general thing, the usual unit voltage of series arc circuits is higher than the primary voltages commonly used in stations, so that step-up transformers would quite frequently be required.

MR. FOSTER:—In a case of that kind, one large unit would be all that would be necessary, and the various circuits could be taken from the secondary or higher pressure side, each circuit to be governed by one of the regulators.

MR. WAIT:—Yes, if you wanted to do that, it would bring the transformer cost down.

MR. FOSTER:—We are considering the case particularly of a station doing arc lighting exclusively. This is the condition most favorable to a direct current system.

MR. WAIT:—In the conclusion, however, it is stated that if the plant is for an arc lighting business alone, the conditions are more favorable to the direct current plants. The figures for such an arc plant will not vary sufficiently from those in the tables to make it worth while to get up another set.

MR. FOSTER:—Mr. Boyer and Mr. Merrill have cited instances of large central stations operating a series of alternating arc lamps. The station Mr. Boyer spoke of, at St. Louis, is furnishing in the neighborhood, I believe, of 3,000 lights, with power and incandescent lighting from the same generator for the series arc lighting, with minutely divided secondary coils. The regulation is accomplished by cutting in or out these coils to keep the current constant. This regulation is done at present by hand. There is no reason, however, why this could not be accomplished automatically. The power factor in a system of this nature would be practically constant at all loads, depending upon the arc lamps used. With the best Manhattan lamps, I am advised that they get a power factor of 90 per cent. Therefore, with an automatic regulator for the transformer, and a good lamp, you could maintain a high-power factor at all loads, and have an excellent system in every particular. With this regulation at the transformer, you will understand there will be no necessity for a regulator similar to the Manhattan or General Electric type.

They are using transformers in St. Louis similar to these I have just described, without the automatic regulation. These transformers were installed and perfected, I believe, previous to the introduction of the Hartford and Manhattan systems.

Mr. Wait:—You will notice that such a system is somewhat in the nature of a cross between the inductive regulator and constant-current transformer systems shown in the tables; that is to say, there is a transformer, which, by the varying relation of primary and secondary, gives the range of voltage desired, while the current is maintained constant under steady conditions by the inductive resistance of the circuit.

It is seen that both the constant-current transformer systems and the inductive-regulator systems show very good economy, as far as everything but the arc itself is concerned. The whole question is practically between the direct and alternating arcs. It is quite evident that a station arrangement like that in St. Louis has a great many advantages over any plant where the dynamo and engine units have to be subdivided into a great many more types and sizes. The question is not one of comparing stations, but of entire systems, including the arc itself, and the contention is made that for a great many plants the superior efficiency of the direct-current arcs will more than make up for the corresponding loss in the station.

I have had some reports on the relative values of the lamps in St. Louis, but they vary so much that it is not worth while to mention them. That is, you find some people who will say that the alternating lamps give very much better light than the direct-current. Another man claims to have made photometric tests from which he found that the alternating lamps were not giving half the power that the direct-current lamps were.

Mr. Foster:—I don't mean to get into a discussion of the relative merits of the different lamps, but as to the comparative systems applicable to the trade. It is a fact, I believe, that the great majority of plants, taking small and large together, are operating alternating machines. It is a fact that a plant can be installed with series arc lamps so that the power factor will be practically constant, and a very high power factor at that. And the lamps as Mr. Merrill says, are quite as simple as the direct-current lamps.

Taking that into consideration, it seems to me that purely from the commercial side of the question, it is a better general proposition than the installation of separate arc machines for the series lighting with an alternating plant for the incandescent lighting. I don't believe that anyone wants to question the statement that a series system, either alternating or direct, is preferable to the multiple system; that is, putting the regular lamps in multiple on 110 volts.

Mr. Wait:—There is no doubt, whatever, that a station having all alternating machinery is better than a mixed one, but the relative amount of light from the arcs should be taken into consideration.

[Adjourned.]

AMERICAN INSTITUTE OF ELECTRICAL ENGINEERS.

New York, November 22d, 1899.

The 137th meeting of the INSTITUTE was held this date at 12 West 31st Street, and was called to order by President Kennelly at 8.15 P. M.

THE SECRETARY:—At the meeting of Council held this afternoon the following associate members were elected:

BAUGHER, E. C.	Engineer of Construction, Westinghouse Elec. & M'f'g. Co., 120 Broadway, New York.	R. D. Mershon. F. N. Waterman. Chas. F. Scott.
BAUM, FRANK GEORGE	Assistant to Chief Engineer, (Dr. F. A. C. Perrine) Standard Elec. Co., of Cal., 23 Nevada Block, San Francisco, Cal.	F. A. C. Perrine. F. V. T. Lee. Clem. A. Copeland
DOWNES, LOUIS W.	Vice-President and General Manager, The D. & W. Fuse Co., Providence, R. I.	F. V. Henshaw. W. C. Woodward. Gano S. Dunn.
EDWARDS, CLIFTON V.	Attorney-at-Law and Solicitor of Patents, 220 Broadway; residence, 114 W. 114th St, New York.	E. C. Davidson. F. W. Roller. R. T. Lozier.
GIBSON, GEO. H.	Assistant Editor, *Engineering News*, 220 Broadway; residence, 209 E. 14th St., N. Y. City	P. B. Delany. Chas. F. Scott. John J. Swann
GRANT, LOUIS T.	General Manager, The Hilo Electric Light Co, Box 160, Hilo, H. I.	F. F. Barbour. J. A. Lighthipe. F. A. C. Perrine.
HANSON, ARTHUR JAMES	Lawrence & Hanson, 3 Wynyard St.; residence, Drunnmoyne, Sydney, N. S. W.	J. S. Fitzmaurice. G. J. Fischer. R. W. Pope.
INSULL, MARTIN J.	2d Vice-President and General Manager, General Incandescent Arc Light Co.; residence, 262 W. 83d St., New York City.	T. C. Martin. W. D. Weaver. J. W. Lieb, Jr.
JACKSON, E. D.	Engineer, Youngstown Telephone Co., Youngstown, O.	W. E. Goldsborough R. W. Pope. H. B. Smith.

LAYMAN, W. O.	Assistant Manager and Treasurer, Wagner Electric M'f'g Co., 2017 Jackson St., St. Louis, Mo.	R. B. Owens. W.E.Goldsborough D. C. Jackson.
LUNDIE, JOHN	Consulting Engineer, 52 Broadway, New York City.	F. J. Sprague. Louis Duncan. C. T. Hutchinson.
PENDELL, CHAS WILLIAM,	Post-Graduate Student, Mass. Institute of Technology, 207 W. Newton St., Boston. Mass.	Chas. R. Cross. Wm. L. Smith. Wm. L. Puffer.
RAUB, CHAS. B.	Electrical Engineer, Engineer Corps, Newport, R.I.; residence, New London, Conn.	W. R. C. Corson. H. E. Heath. T. C. Martin.
ROBERTS, ALLEN DAVIDSON	Electrical Inspector, City Council, Kingston, Jamaica.	S. Dana Greene. T. C. Martin. E. E. Boyer.
RUSSELL, H. A.	Sales Agent, General Electric Co., residence, 302 Laurel St., San Francisco, Cala.	J. A. Lighthipe. F. F. Barbour. F. A. C. Perrine.
SCHWEDTMANN, FERDINAND	General Superintendent, Wagner Electric M'f'g Co., 2017 Locust St., St. Louis, Mo.	R. B. Owens. W.E.Goldsborough D. C. Jackson.
SCUDDER, HEWLETT, JR.,	Assistant to Prof. Henry M. Howe, residence, 21 E. 22d St., New York City.	F. B. Crocker. G. F. Sever. R. W. Pope.
STOUT, JOSEPH SUYDAM, JR.,	Inspector, Edison Electric Illuminating Co., residence. 35 East 67th St., New York City.	Leonard Waldo. A. R. Ledoux. C.T. Hutchinson.
WHITNEY, CLINTON EUGENE	Draughtsman, with Geo. T. Hanchett; residence, 61 W. 114th St., New York City.	Geo. T. Hanchett T. C. Martin. W. D. Weaver.
WILKES, C. M.	Engineer, D. H. Burnham & Co., 1142 The Rookery, Chicago, Ill.	B. J. Arnold. H. A. Foster. R. B. Owens.

Total 20.

The following associate members were transferred to membership:

Approved by Board of Examiners September 8th, 1899

CUMMINGS C. CHESNEY, Chief Electrical Engineer, Stanley Electric Mfg Co. Pittsfield, Mass.

CAPT. ACHILLES DE KHOTINSKY, Late Chief Electrician and Torpedo Officer, Imperial Russian Navy, Northern Electric Co., Madison, Wis.

THE PRESIDENT:—The first business of the evening will be the reading of a paper entitled "Test of a 300-Kilowatt Direct-Connected Railway Unit at Different Loads," by Edward J. Willis. Mr. Willis not being here, we will have the pleasure of hearing this paper from Prof. Sever who has kindly consented to read it for us.

A paper presented at the 137th Meeting of the American Institute of Electrical Engineers, New York and Chicago, November 22nd, 1899

TEST OF A 300-KILOWATT DIRECT-CONNECTED RAILWAY UNIT AT DIFFERENT LOADS.

BY EDWARD J. WILLIS.

The test given below is not offered as presenting any novelties either in the manner of the test or in the results attained, but is rather given as a reliable instance to be added to the already accumulated data of this character. It is believed by the writer that where it is possible, it is advantageous that the INSTITUTE should publish reliable data on the water, steam and coal consumption, especially of the direct-connected units in actual commercial operation. In 1896 the writer designed and there was installed under his supervision a steam installation of two 300-kilowatt direct-connected railway units for the Richmond Traction Company. On March 30th, 1897, as superintendent of that road, he had opportunity to test the steam, water, coal consumption and electrical output of one of these units at different loads and it is this data which is listed below.

DESCRIPTION OF UNITS.

Boilers.—One 300-H.P. Campbell & Zell water tube boiler with 3000 sq. feet submerged heating surface.

Engine.—16x30x42 Hoover, Owens & Rentschler horizontal tandem compound condensing engine, double eccentric, 100 R.P.M.

Generator.—300-K.W., 6 pole, steel frame, General Electric railway generator.

Piping.—The piping is practically what is known as standard, being an 8-inch spring from boiler to 14-inch steam-header and 6-inch spring from steam-header to throttle. A short 14-inch exhaust pipe exhausts through a Hartford heater into a Deane jet condenser.

Card Numbers.	Time.	Boiler Pressure.	Receiver Pressure.	Vacuum.	Feed Temperature.	Throttle Temperature.	Injector Temperature	Overflow Temperature.	Draught Flue Temperature	R. P. M.	Mean Pressure H. P. Cylinder.	Mean Pressure L. P. Cylinder.	Volts.	Amperes.	Water Feed.	Coal Feed.
1 & 2	12.10 P. M.	108	4 lbs.	25½	190½	343	65	90	360	101	25.76	6.55	550	205	-	
3 & 4	12.30 "	110	5 "	26½	190	343	65	90	360	101	29.75	6.25	550	210		
5 & 6	12.45 "	118	6 "	26½	190	343	65	91	350	101	24 37	6 60	550	200		
7 & 8	1.00 "	125	7 "	26½	186	350	65	91	320	101	29.50	6.42	550	195		
9 & 10	1.15 "	115	5 "	26½	186	343	65	91	320	101	28.12	6.40	550	192		
Totals........		576	27	131½	942	1722	325	453	1710	506	137.50	32.22	2750	1002	3469	345
Averages.....		115	5 2-5	26½	188	344	65	91	342	101	27.50	6.44	550	200		
11 & 12	1.19 P.M.	112	7 lbs.	26	186	346	65	97	360	101	39 50	8.60	550	298		
13 & 14	1.36 "	115	8 "	26½	185	346	65	100	380	100	39 00	8.90	550	300		
15 & 16	1.50 "	114	7 "	26½	183	340	65	97	400	101	40.00	8.37	550	297		
17 & 18	2.05 "	115	8 "	26½	183	343	65	98	400	101	37.75	8.70	550	300		
19 & 20	2.23 "	115	7 "	26½	183	343	65	98	400	101	41.50	8.25	550	300		
Totals........		571	37	132½	920	1718	325	490	1940	504	197.75	42.82	2750	1497	4912	455
Averages.....		114	7 2-5	26½	184	344	65	98	388	101	39 55	8.56	550	299		
21 & 22	2.25 P.M.	113	10 lbs.	26½	185	341	65	111	400	102	48.75	11 45	550	400		
23 & 24	2.42 "	100	6 "	26½	185	329	65	111	460	100	48.87	11 87	550	400		
25 & 26	2.51 "	115	9 "	26½	185	343	65	111	500	101	46.50	11 15	550	400		
27 & 28	3.10 "	113	8 "	26½	185	342	61	111	500	100	50.37	11.00	550	395		
29 & 30	3.25 "	118	5 "	26½	185	344	61	100	500	100	49.50	10.60	550	393		
Totals........		559	38	132½	925	1699	317	544	2360	503	243.99	56 07	2750	1988	5141	575
Averages.....		112	7 3-5	26½	185	340	63	109	472	101	48.80	11.21	550	397		
31 & 32	3.25 P.M.	110	10 lbs.	26	185	340	61	100	520	101	58.87	15.05	550	500		
33 & 34	3.50 "	110	10 "	26	185	340	61	100	540	101	57.00	14.20	550	500		
35 & 36	4.05 "	110	10 "	26	180	339	61	100	560	101	55.75	14.55	550	500		
37 & 38	4.20 "	108	10 "	26	180	339	61	100	580	101	58.87	14.07	550	500		
39 & 40	4.35 "	110	10 "	26	180	340	61	103	580	101	56.25	14.07	550	500		
41 & 42	4.50 "	110	10 "	26	180	340	61	103	580	101	58.25	14.50	550	500		
43 & 44	5.05 "	110	10 "	26	180	340	61	102	580	101	58.50	14.57	550	500		
45 & 46	5.20 "	110	10 "	26	180	340	61	102	580	100	60.25	14.70	550	500		
47 & 48	5.35 "	110	10 "	26	180	340	61	102	580	101	57.00	14.80	550	500		
Totals........		988	90	234	1630	3058	549	912	5100	908	520.74	130.51	4950	4500	14486	1690
Averages.....		110	10	26	180	340	61	101	567	101	57.86	13.39	550	500		

CALCULATED RESULTS.

LOAD.	POWER.			Evaporation		Coal Consumed.			STEAM.			EFFICIENCIES.		
	Indicated H.P.	Electrical H.P.	Kilowatts.	Water per lb. of coal (actual).	Water per lb. of coal from and at 212° F.	Per indicated H.P. hour.	Per electric H.P. hour.	Per K.W. hour.	Per indicated H P. hour.	Per electric H.P. hour.	Per K.W. hour.	Indicated H P. per electric H.P.	Electric H.P per indicated H.P.	Indicated H.P. per K.W.
200 Amperes.	216	146	110	10.05	10.71	1.45	2.18	2.90	14.8	21.9	29.1	1 48	.68	1.96
300 "	299	220	164	10.8	10.75	1.43	1.94	2.60	15.3	21 9	28.1	1.36	.74	1.82
400 "	373	293	219	8.94	9.53	1.54	1.96	2.63	13.8	17.53	23.46	1.27	.79	1.70
500 "	469	369	275	8.57	9.18	1.66	2.11	2.83	14.25	18.1	24.3	1.27	.79	1.70

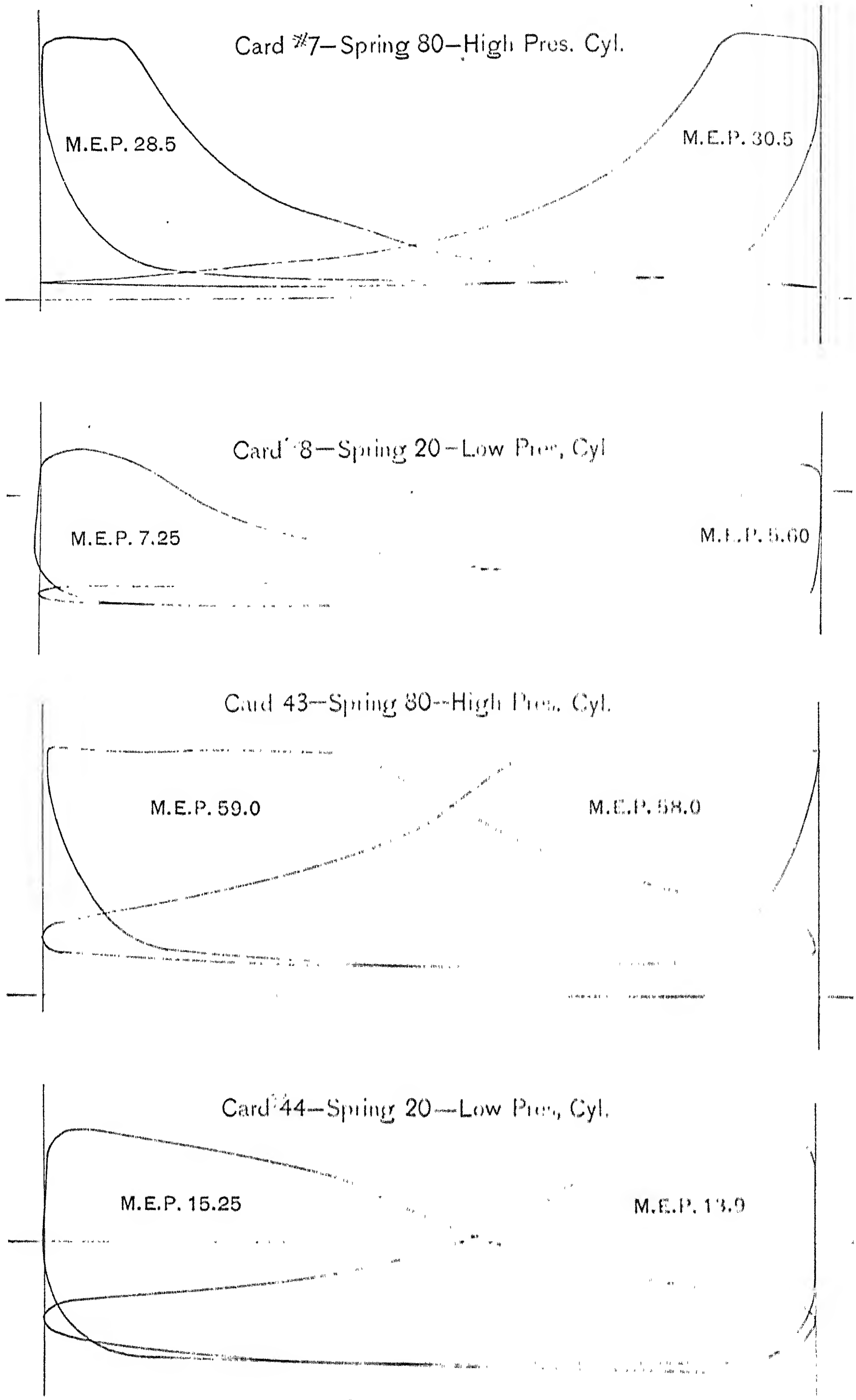
These machines being standard commercial articles, members of the INSTITUTE can readily obtain catalogues, descriptions and detailed blue prints, and it is therefore not thought necessary to burden this paper with lengthy and minute details and data thereon.

METHOD OF MAKING TEST.

A large water rheostat was provided, capable of handling the full output of the generator, and a Weston ammeter and voltmeter were placed upon the circuit of the generator. By this means the output of the generator could be fixed, maintained and measured at any desired point. The system of piping permitted the feed pump and condenser to be operated by a separate boiler, so that all the steam generated by the boiler passed through the engine. All valves were tested and made tight. A Worthington hot-water meter was thoroughly overhauled before the test and was accurately tested before and after the run. The water and steam consumptions are those given by this meter. The coal fired during the test was Pocahontas run of mine, giving probably 13,000 B.T.U. Draught at grate during run five-eighths of an inch. Indicator cards were taken as nearly every fifteen minutes as possible off both ends of each cylinder and also simultaneous readings of coal, water, electrical output and the other items mentioned in the table. Sample cards are shown below. The object was to determine the steam, water, coal consumption and indicated horse-power of this unit at different loads. The load was as follows: For one hour at 200 amperes, the next hour at 300 amperes, the next hour at 400 amperes, the next hour at 500 amperes, and it was intended to place the load the next hour at 600 amperes, but under such steady load the machine became too warm and instead the load was continued for two hours at 500 amperes.

REMARKS.

It is regretted that the point of load could not be carried higher, but it is to be remembered that railway generators are usually designed for fluctuating loads and that such steady loading as given in this test is likely to cause considerable heating. It is further unfortunate for the sake of accuracy that on account of the need of the generator for the operation of the load, the duration of each test could not have been made greater,



INDICATOR CARDS.

since the determination of coal and water consumption for such short periods of time are almost always attended with unavoidable inaccuracies. The water rheostat was composed of two sheets of boiler plate 5′x6′ each. By means of soda the conductivity of the liquid was brought to the desired point. With light loads and before the water commenced boiling completely, there was some fluctuating in amperage, but after the water got to boiling thoroughly, the load could be maintained perfectly steady. At 500 amperes there was about 15 square feet of each plate submerged. The water evaporated by the boiling was replaced by a hose connection and the water level in the rheostat tank thereby maintained constant. The writer would state that in his experience with rheostats of any size, if a steady load is required, it is better to let the water come to a boil and the plates remain steady, replacing the evaporated water with a running connection, than to attempt the continual raising and lowering of the plates.

This test was made to confirm the writer's opinion that it was advisable with railway units carrying fluctuating loads to install a double eccentric under-sized engine, and that better running economy could thereby be obtained than by the installation of the usual larger and more expensive engine. It will be noticed that the engine gave its best steam economy at about 400 amperes, and as the average load on this engine is lower than this, the wisdom of the installation for this plant of so small an engine for the 300 kilowatt units is plainly shown.

Discussion.

The President:—The paper before the Institute is a brief summary, as you have heard, of a test of a 300-kilowatt direct-connected railway unit, commencing with the steam consumption and terminating with the output at generator terminals. The time was when the dynamo was a thing very distant from the engine; many feet perhaps of countershafting and belting separated the two. As the dynamo got bigger and more pretentious, the belting and the countershafting shortened, and now with the dynamo at the size we find it in common practice, the distance between the two has so far diminished that the two form parts of one whole machine, and it is becoming more important to study the unit and the machine as a whole. The paper is therefore interesting from that standpoint and a discussion of the paper is now in order.

Mr. Geo. F. Sever:—I would say in connection with this paper, that it seems as if a very important feature had been omitted from the test, and that is the temperature of the dynamo during the run. I fail to see a record of it in the table. It seems to me that this feature is just as important and perhaps more so than almost any other of the items included in the table. I think, that in presenting this matter to the Institute as a record, such an important measurement as the temperature ought to be stated.

Mr. Willis: [Communicated] The temperature of the dynamo during the run would have been given, had not the thermometer used for this purpose been accidentally broken at the end of the second run, and the location of the plant rendered it impossible to replace it in time for the test.

Mr. Geo. Hill:—In first glancing over the table it appeared that in the section labelled "calculated results" that an error had been made. Further examination shows that the results as stated are substantially correct. The points which seem to be brought out by the paper are:

1st.—That in all direct-connected work where the load carried by the generator violently fluctuates, it is economy to design the engine so that it can safely develop the maximum horse power with a late cut-off, the engine cutting off at about a quarter stroke for from 60 to 70 per cent. of rated capacity.

2nd.—The generator has rather a flat efficiency curve, but is certainly not generously proportioned if, as the author states, it became too warm after running for an hour at 500 amperes. Under fluctuating load this perhaps is no objection, if the saving in material carries with it a saving in price, but as between two generators of the same price it would be a disadvantage.

3rd.—While it is economy to use an engine of less rated capacity than the generator would ordinarily demand for constant load, it is not economy to use the boiler of the same rated

horse-power as the engine, the efficiency of the boiler when beyond its rated capacity showing a noticeable falling off. It may not be amiss to call attention to the fact that the setting of the valve of the low pressure cylinder as shown by the indicator cards is bad, the cut-off being much earlier at the right hand end than at the left hand end in each case.

Mr. Willis: [Communicated.] The generator had been running continuously just previous to the testing and was comfortably warm when the test was started which had something to do with the fact of its heating up as stated. The writer has little doubt that the generator would have stood the higher load, but preferred to err on the safe side and not submit the generator to unnecessary temperatures.

Mr. Hill is particularly correct in his remarks about the boiler capacity not being sufficient. The marked falling off of the efficiency of the boilers at heavy loads, to which Mr. Hill very thoughtfully calls attention, was due to a number of the baffle bricks having fallen in. This did not show at the lower loads, but caused the high draft flue temperature and low evaporation shown in the test for the higher loads. The test led to a very careful examination of the boilers for such troubles, which resulted in a thorough renewal of both bridge and baffle walls. After these repairs the boilers showed up considerably better when heavily loaded.

Mr. C. O. Mailloux:—I think it would be desirable in future in tabulating results of this kind to include the friction tests of the engine, so that one might have a clue as to the mechanical efficiency of the engine itself. I am led to this statement by noticing the last column of the calculated results which give indicated horse-power per kilowatt. Of course here we are dealing with a quantity which has no reference whatever to the coal consumption. It is purely a ratio of the amount of indicated horse-power to the net electrical output, in kilowatts. Now it would seem that for an engine of that size the values ought to be very much lower, if the engine or the dynamo did not have excessive friction. I have always made it a practice in making tests of this kind to notice the indicated horse-power per kilowatt, because it is a quantity that is really of great interest, since it takes into account not only the efficiency of the dynamo but that of the engine as well, and an engine which would have a very low friction load would of course materially help the efficiency of the unit as a whole. In a unit of this size I would not expect to find a value higher than about 150 or 155. I find that in a well-arranged, direct-connected unit even at small sizes, from 50 to 150 or 250 K. W.—it very seldom exceeds 1.6 at full load. In this case even at 500 amperes, which is considered very nearly full load, it was still 1.7., which, it seems to me, is a very high figure for a unit of this size. One might expect such a value as that with a dynamo of 25 K. W. direct-connected, but

scarcely with one of 300 K. W. For this reason, it would have been interesting to give the friction cards showing the friction load of the engine with brushes on and with brushes off, so that one might have some clue as to where some of this energy has been lost, and over what portions of the generating set it is distributed.

MR. E. J. WILLIS [Communicated.]: Mr. Mailloux is correct in his statement that the indicated horse-power per K. W., as given in the test, is high. As stated in the paper the author has not offered the paper as one showing especially high economy, but as one giving reliable results obtained under usual running conditions. The friction load of engine with brushes down was 51 horse-power. The friction load with brushes up was not determined.

THE PRESIDENT:—Is there any further discussion of this paper? If not, we will pass to the second item on the programme for the evening, which is a topical discussion on the "Possibilities of Wireless Telegraphy," and we will call upon Prof. Fessenden to open that discussion.

A Topical Discussion at the 137th Meeting of the American Institute of Electrical Engineers, New York, November 22nd, 1899. President Kennelly in the Chair, Chicago, Local Honorary Secretary Pierce in the Chair.

THE POSSIBILITIES OF WIRELESS TELEGRAPHY.

[A TOPICAL DISCUSSION.]

PROF. REGINALD A. FESSENDEN:—Whilst there are many advantages in living in a city in which there is a widespread and intelligent interest taken in scientific work, there is this disadvantage, that when any discovery of a striking nature is made, the professor's friends and the directors of the institution he is connected with expect him to immediately lay aside his own work; work which he may personally consider of much greater importance than the novelty of the hour, and to assist in the development of the new discovery.

Having thus been forced, some years ago, into X-ray work, with much loss of time and very little results to show for it, I considered myself proof against the seductions of liquid air and wireless telegraphy. Consequently when, having suggested to one of the editors of the *New York Herald* that they report the international yacht race by the new method, I was invited by them in December, 1898, to undertake the work myself, I declined and put them in communication with Signor Marconi.

It was found later, however, that there were some exceedingly interesting questions, which had not been solved, in this connection. In none of the work hitherto done had any *exact measurements* of the quantities involved been made. Consequently many points were still in doubt. The theory of electromagnetic waves had been well and thoroughly covered by Heaviside. But if the theory, as put forward by him, is correct, it is extremely difficult to account for Marconi's law, that the distance of transmission, other things being equal, varied as the product of the heights of the sending and receiving wires. And yet the great experimental ability shown by Signor Marconi in his admirable work rendered it necessary to suppose that in forming our theory we had omitted some consideration which, known to Marconi and his assistants, were as yet unknown to us.

Unfortunately the receiver in general use, *i. e*, the coherer, is very ill adapted to quantitative measurements. A simple and

very sensitive form of receiver having having suggested itself, a few experiments were made in June, but the matter would have been dropped had it not been that my former assistant and present colleague, Professor Kintner, with the greatest of kindness offered to help me, and with the aid of his invaluable constructive and experimental ability, it has been found that it will be possible to carry the work to a successful conclusion, though as yet but a few of the points which it is proposed to investigate have been covered, and these not as yet fully.

As we have already had one paper this evening and there are some other speakers to follow, I will only touch on one or two points which may be of interest, and on them as briefly as possible. I shall leave the discussion of the question of long distances to others, and shall give, as my contribution to the discussion, an account of the first quantitative measurements which have been made in this line, and some of the results obtained.

I will first show a model which is supposed to represent the form of the waves which are concerned in the phenomena, so far as we can tell from the latest theories, (or rather from the theories on the subject, because some of them are not of recent date. Heaviside showed a number of years ago what the general shape of these waves ought to be.) I will then show and describe some forms of receivers which I have designed, and which have shown themselves especially valuable for making quantitative measurements. Of course Marconi's apparatus is peculiarly adapted for practical work; but it is not so well adapted for giving exact measurements of the amount of energy or voltage. Moreover, it is not nearly so sensitive as the receivers I shall show. I will then state briefly how my own experiments have agreed with the theory and take up one or two practical points which have developed in the working.

The piece of wire and pasteboard here shown [Fig. 1,] is supposed to represent the waves: A is supposed to be the sending apparatus; the pole which is connected to the induction coil. When the break of the induction coil occurs the vertical conductor is charged, and the electrostatic lines, according to Heaviside, come out and strike the ground at B. I don't remember exactly into what detail Heaviside goes. He gives the general shape of it. The electrostatic waves come out all around, of course; this model being merely a slice out of the wave front. The model represents the condition of affairs when, after some waves have been emitted, the tension is a maximum. As soon as the spark passes between the two terminals of the induction coil there is a conducting path formed through the heated air to ground. The ends of the lines can now slide down the conducting wire to ground and form a sort of a half hoop, as shown at C,—and travel outward. The whole thing, for a cylinder, is worked out in Prof. J. J. Thomson's supplement to Maxwell.

As it goes out, as you will see from Fig. 1, the rear ends of the half hoops bend more and more in, as at D, until finally when you get some distance away from the exciting source the fronts and backs of the waves are parallel to one another; and form parts of concentric spheres whose center is the originating point A.

This kind of wave was first experimented with by Lodge, so far as I know. It differs from a true light wave in this, that the two ends of the wave slide over the conductor. If you can imagine the pasteboard strip, E, a mirror, and suppose that the other half of the wave was underneath it at X, as if it were its reflection in the mirror, you then get the full wave, such as you get from light, or from the regular Hertz oscillator. But, as I say, this differs from it, in that the ends of the electrostatic lines slide along the surface of the conductor as they go

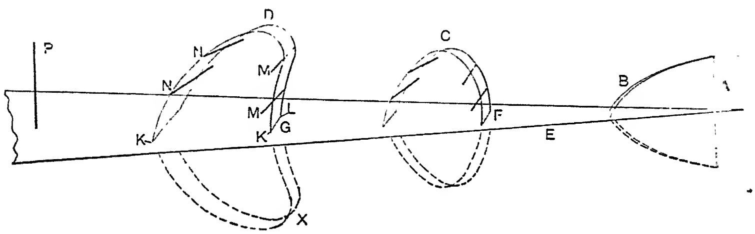


Fig. 1.

out. The wave-length is approximately four times the height of the exciting pole. The model is made to scale. The wave-length from F to G being four times the height of A. Consequently, if you double the height of your pole you double the length of the waves.

K. L, represent the electrostatic lines. M. N. represent the magnetic lines, sticking out at alternate ends, to indicate their direction. When a wave in going along strikes a conductor, such for instance as the wire P, the magnetic lines cut it and in cutting it they create a voltage in it. This voltage, incapable of being supported in the conductor itself, concentrates itself down at the bottom of the pole across the gap of Marconi's receiver and sparks across, reducing the silver sulphide or oxide, and when the current has once passed, the insulation being destroyed, the relay works. The periodicity of these waves is pretty high. Traveling at the same velocity as light, we find that

if we have a 150-foot pole the periodicity comes out about three millions per second. If we take a pole such as would be used to send signals across the ocean, a thousand feet high, we find that the periodicity is 400,000 per second.

Another point in which these waves have a great advantage over the ordinary light waves is that they follow the surface of the conductor. If, for instance, we have a hill, the waves slide up and over that hill. It is for this reason that I think we can never hope to obtain anything from direct Hertz waves, thrown by a reflector, because those will not work that way; they go straight out, and the only chance that they have is through striking the water and being cut off or reflected a little bit and then sliding along in the same way as the Lodge waves.

Since these waves travel over the surfaces, the surface must be a conductor, and this naturally has considerable to do with the strength of the waves received. On land, the waves are frittered out very much more quickly than they are on water. For sea water and land the proportion seems to be about three to one, so far as one can judge from Mr. Marconi's experiments. I have made none myself as yet. But I have noticed that there is a tremendous difference on land on different days. On a muggy day you get perhaps five to ten times the throw of the receiver that you will on a dry day. Ice does not seem to make much difference, so far as we can tell; possibly for the reason that in that case the wave goes right down to the warm ground underneath the surface and travels along there, and of course the ice being of very high specific inductive capacity it would not hurt matters very much.

It is interesting to calculate what the effect of distance ought to be. In the present case you see that at twice the distance you have the same number of lines on the wave front; but in order to get the whole wave front, your pole has got to be twice as high. In other words, to get the same voltage piled up on the receiving conductor over at P you must have a pole just twice as high as it has to be at C. Or, for a given height of pole the voltage available decreases directly as the distance, and with a receiver like Marconi's which depends mostly on the voltage—the coherer would have to be twice as sensitive to work at twice the distance, the pole being of the same height, or in other words at double the distance a given coherer should be worked with double the spark-length at the sending end. The energy, however, is only a quarter as much for a given height of pole. At the receiving end, if you double the height of the pole you would get double the voltage on it. At the sending end, if you double the height of the pole *and at the same time double the length of the spark*, then you will get a wave exactly the same, except that all its linear dimensions are doubled, and you will get double the voltage at the far end. So that theory indicates

that Marconi's rule should be modified to this: "If you double the height of the receiving pole and at the same time double the height of the sending pole and also double the length of the spark, the distance at which you can receive should be four times as great." I cannot find that Marconi's rule ought to hold *unless you also double the voltage of the spark*, because the effect of doubling the height of the sending wire ought not theoretically to have nearly as much effect as doubling the height of the receiving wire.[1]

The energy, however, comes out somewhat differently. If you double the height of the pole at the far end, you get double the voltage. If you double the height of the pole here, and at the same time double the voltage, you will get four times the energy near the origin in a given slice. But if your receiving pole is over at P and the magnetic lines come along and strike it, the conductor gathers in a certain fraction of the width of the wave and this fraction is approximately, as near as I can figure it, about one-seventh of the wave length, the amount of energy that the conductor scoops out of the wave front depending on the length of the wave itself. Consequently, when you double the height of the sending pole and double the wave length you scoop out a bigger area, twice as much, doubling the energy, but not the voltage received. Take your receiving pole, its height here gives you voltage. Then lay your sending pole crosswise, like this, so as to get a rectangle; the product of these two is proportional to the total amount of *energy* per wave. If at the same time you have doubled your voltage you would get eight times the energy, but you only have half as many waves per second.. So that using a receiver which works by energy and not by voltage, the distance to be sent ought to vary as the product of the heights of the poles if the spark-length is proportional to the height of the sending pole.

I will now describe some of the instruments that I have made. The first instrument is shown in Fig. 2. It is heavier than necessary, but is nevertheless quite sensitive. The ring A is a bit of No. 26 wire hung on a quartz fibre with a mirror M attached. B is the collecting wire. The magnetic lines strike this and make a voltage, and the resultant current goes around this coil C, around through the coil D and then to ground. The closed ring is at 45° to the coils C and D. The principle on which it works was first discovered by Elihu Thomson. The current coming in through C and D makes an alternat-

1. At the close of the discussion, one of the officers who was engaged on the recent tests of the Marconi system for the Navy here, informed me that this was the case, *i. e.*, that it was found in practice that if two vessels had wires of different lengths, communication should be carried over a longer distance when the vessel with the higher pole was the receiver than when it was the sender. This is a very satisfactory corroboration of the theory.

ing current field. That alternating current field sets up a voltage in the ring A. The voltage in the ring makes a current in the ring, and the current in the ring reacts on the original magnetic field. The consequence is that the ring tends to turn. It is a very nice galvanometer to work with. You have a quartz fibre. Your zero always stays the same. There is nothing magnetic about it. For the best results it should be connected with a condenser right across it. Of course, the reason of that is obvious. You generate a voltage in it, and if you have got a condenser as at F, then for a given voltage you can get a considerable current in the coils, that current simply depending on the resistance of the coils, and you do not fritter any energy away in current up and down in the receiving wire; whereas if you

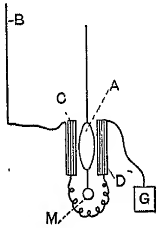


Fig. 2.

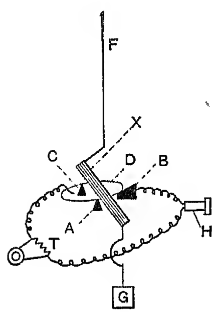


Fig. 3.

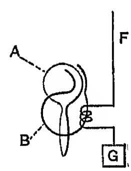


Fig. 4.

put a condenser in series with the instrument, your whole current flows through the receiving wire, tapering off, of course, as it goes up, and you lose a great deal of energy in resistance. This is the first and simplest form, and is the form that is used mostly. It works very nicely.

Fig. 3 is a form which I have tried a little but have not had time to work out very thoroughly: A is a little block with silver wire on it, B is a V-shaped piece of carbon. C is another block with wire on it. D is a closed silver ring which is laid right on top of A, B and C, so that it almost balances on A and C. F is the collecting wire and the current comes down from the pole and goes through the coil X as before, and out again to ground, with a condenser across X as before. You put this ring D on so that it lightly rests on the microphonic contact B. T is a source of A. C. voltage, very low, and H is a telephone. When the current passes through the coil X, it presses the ring down and the previous slight noise in the telephone is made louder, and on the duration of loud noise depends whether the signal is

a dot or a dash. This seems to be pretty nearly as sensitive as this other instrument here.

The third instrument which is more sensitive still, but which I have not had time to work very much on, is shown in Fig. 4. This looks, at first, a little like a single-phase motor. A is a wire ring made in a figure 8 form. B is a piece of iron wire bent into the shape shown. As a matter of fact, in the instrument made, this wire went three or four times through A. F is the collecting wire. The magnetic flux is linked with a part of the ring, and the ring itself has one edge in the magnetic field. The result is, a voltage is induced in the ring, and the current flowing around in the ring acts on the air-gap flux and the ring tends to twist. It is quite sensitive.

So far as the results obtained, I would say that they seem fairly well to agree with the theory, but as yet not so well as I could have hoped. For instance, doubling the spark-length, you ought to get four times the deflection; whereas I did not get that, though, perhaps, this was due to a weaker stream of sparks. Here is a record of one set of observations made:—

When the spark-length was 40, the deflection was 60.
When the spark-length was 32, the deflection was 62.
When the spark-length was 24, the deflection was 33.
When the spark-length was 21, the deflection was 30.
When the spark-length was 13, the deflection was 10.
When the spark-length was 9, the deflection was 6.
When the spark-length was 5, the deflection was 3.

And so on down. The deflection does not quite vary as the square of the spark length, and it ought to.

The time during which the spark stream is made, seems to influence the deflection very nearly as it ought to. For instance, one result was: Time during which the spark was occurring, 2 seconds, deflection was 20. Time 10 seconds, deflection 94.

The results obtained are merely preliminary, and before giving them in detail, I want to repeat them under better conditions. To get accurate results you must have a good ground. You must go for the best results to some place near salt water. The ground seems to depend a good deal on the state of the weather, as I say. Sometimes running a wire direct from one station to the other will not improve the ground more than 20 or 30 per cent. At other times, the ground will go away back on you. And it does not seem to depend on contacts, because all the contacts made were amalgamated with mercury.

The results are not always consistent. Sometimes you get five results the same. Then suddenly, owing to something in the sparks you will get a kick five or ten times as big. One curious thing I might mention was that we got some very hard kicks while we were working. Finally we traced the cause up to the fact that about three or four hundred yards away there

was an electric street railroad, and as a car went around a certain corner there was an arc owing to the trolley sparking over a contact. Ever time that arc occurred we got a tremendous kick. The trolley itself seems to act as a sending pole.

The following are the points which have been or will be investigated:

1. Effect of change of spark-length.
2. Effect of different kinds of break.
3. Effect of condensers in sending wire, in shunt to air-gap.
4. " " in series.
5. " " " with receiving wire.
6. " " in shunt to receiver.
7. " varying capacity of sending wire.
8. " " " receiving wire.
9. " " heights of sending and receiving wires.
10. Efficiency of different portions of sending and receiving wires.
11. Efficiency of different kinds of grounds, especially of what may be called the crow-foot ground.
12. Efficiency of different forms of receivers.

Some work has been done in nearly all of these lines, but it has been found necessary to turn all our attention to the question of a reliable ground, and when this is settled we shall return to the other questions.

I have to express my sincere thanks to Professor Kintner for his invaluable assistance, without which it would have been impossible for me to have taken up the subject.

Mr. W. J. Clark:—I don't know that I have very much to say this evening on the subject of wireless telegraphy after listening to the very interesting account of Prof. Fessenden's experiments. Perhaps the best thing I can do is to give you my experience. I suppose you all know that during the yacht races I had the pleasure of being associated with Mr. Marconi in reporting the races for the *New York Herald*. During that time Mr. Marconi had a receiver on the Highlands at Navesink connected with a wire about 115 feet in height. He also had a receiver on the cable boat *Mackay-Bennett* connected to a wire I think about 115 feet in height. I had a transmitter and receiver on the *Grand Duchesse*, 115 feet of wire, and a Thomson induction coil for my transmitter. I used the ⅞ in. balls which are always furnished with the Thomson Roentgen ray apparatus, for my oscillator. The balls were in very bad shape. They had been used for a long time without either being cleaned or polished, and in spite of this fact we had no trouble whatever in sending the signals in to the cable boat and also in to Navesink station. Mr. Marconi was on the *Ponce*, and had no trouble whatever in reading our signals. I have constructed two different styles of receivers. One is a very expensive instrument, provided with a great many adjustments for con-

venience. Another is a smaller instrument intended principally for demonstration work. I made a test with my expensive instrument, and then with the other one, and I found that the simpler instrument gave me much better results over the long distance, and some days I was receiving from Mr. Marconi at the rate of between 10 and 15 words per minute from a distance of fifteen miles. I have noticed one thing in experimenting; that it is necessary to have the capacity of the two vertical wires equal as nearly as possible. During the recent electrical exhibition I was asked to send the Governor's message from the Pulitzer Building to Madison Square Garden. I was only given about one or two days at the outside to get ready, and of course that meant a great deal of work in a very short time. We placed about 260 feet of wire on the Pulitzer Building and about the same amount on Madison Square Garden, placing the transmitter in the Pulitzer Building, and the receiver at the Garden. We found it impossible to get any results whatever. We could not get the slightest sound from our receiver, although it was a very sensitive instrument, and the transmitter was a very powerful one. Our wire was rubber covered, and thoroughly insulated from each building. The way we insulated these wires was by hanging them from a rod of hard rubber about two feet in length and about an inch in diameter. We used a *large* rubber rod in order that it might be able to resist the strain upon it. At the lower end of the wire we used a similar rod,and then took a tap from our wire and led it in through a window on whichever floor we happened to have our instrument. After the exhibition was over, I made a test between Madison Square Garden and our laboratory, which is not over a block and a half distant. Using about 260 feet of wire on the Garden and about 60 feet at the laboratory, I could get no results whatever, no matter which end I placed the transmitter on, and I was rather puzzled. I found, however, in conducting some other experiments on the bay, and also in the city, that it was absolutely necessary to have the two wires of about the same capacity. We have been able to transmit altogether, aside from what we did at the yacht races, to a distance of about seven miles, and our signals were very clear, indeed. However, I must accord to Mr. Marconi the credit of having by far the best apparatus, better than any I have seen in America, including my own. His receiver is extremely non-sensitive. The receiver which Mr. Marconi was using at the races was a receiver which, under ordinary conditions, that is, under the conditions under which I have experimented, would not receive a message from my transmitter at a distance of more than a mile. Now, Mr. Marconi tells me, at least he hints to me, that the way he accomplishes this result is by measuring the capacity of each wire, and having them precisely alike.

I have recognized for a long time that the coherer was a very

troublesome piece of apparatus, and that it was something which we should try to get away from as much as possible. Consequently, I have been experimenting for some little time on a new kind of receiver. I should have said that when Mr. Marconi was here, although his instrument was receiving from his own transmitter at the rate of but from 18 to 22 words per minute, he said to me that he thought his receiver had about reached the limit of the transmitting operator's speed. I would have liked to have the opportunity of trying to transmit to his receiver using our American Morse code, but that unfortunately was impossible, because Mr. Marconi's assistant could not decipher that code. Now, I I have found that by using a new arrangement in the receiver and doing away with the coherer entirely, that we are able to transmit at a very much greater speed; in fact, that we are able to transmit as fast as we can operate the key. I have only experimented with this very recently, only during the last few days; that is, I have only brought it to a state anywhere near perfection during the last few days.

Another peculiarity I have observed is this: that in the transmitter we get the best results by far, when the secondary of our coil is wound with the finest possible wire. You know when the X-rays first came out, everybody said that we must wind our secondaries with a much coarser wire than they were wound with before. The consequence was that nearly everybody was provided with induction coils with coarse secondaries, giving apparently a heavy spark. Of course we all experimented with those coils because they were convenient; but I happened to have access to one of the old style coils with very fine wire on the secondary, No. 40, I think, and I found the results were very much superior to what I was able to get with the coils wound with a heavy secondary, although the coil with the fine secondary was a very much smaller one, very much shorter spark-length than the coil with the coarse secondary. I think from this, that there are indications of the fact that the balls of the oscillator are not necessary at all. You will remember that when Mr. Marconi first began to experiment, he used balls of four inches in diameter, and stated in some of his publications at that time that the larger the balls to a certain extent, the better the result. Now for 110 miles transmission he is using balls one inch in diameter, and if I had my apparatus here to-night, I could show you that it is quite possible to transmit signals across this room with the balls so far separated that you do not get any discharge at all, and I could also prove to you conclusively that waves did not emanate from the spark at the interrupter. I think from all this, as I said before, that the indications are that we will get along without the balls at all or without any spark. When Mr. Marconi was here he had the kindness to visit our laboratory and I was showing him one of our small outfits and showing him how it would operate by opening a motor switch on the wall

with 220 volts and a very small current, and Mr. Marconi expressed his very great surprise that a spark of that kind would work any receiver, because he claimed it was not a static spark.

Another thing I have noticed is this, that for instance if we have a receiver on this table, and a transmitter on the other table, a very small one, say giving a half-inch spark, if we separate the balls to the full distance of one-half inch, we will not get anything like as good results as if we bring them to about one-sixteenth of an inch, and in a five-mile transmission I have found much better results from a spark half an inch in length than from one inch in length; but in each case I was using a coil of 10-inch spark length, so that the distance of the balls from each other would not interfere with the continuity of the spark.

I do not know that I have anything further to say; but before sitting down I would like to ask Prof. Fessenden what kind of spark he has been using in his experiments and what difference he has found, if any, between the heavy spark and the light spark, so to speak.

Prof. Fessenden:—I used an ordinary induction coil for the work. Part of the time I used it with the ordinary break, and part of the time with a Wehnelt break. I did not find very much difference between the two. I found a one one-hundredth of an inch spark to work very well at about 200 yards with 15 ft. poles, and it did not seem to make very much difference what the kind of spark was. I did notice however that when we got a flaming spark, the results were not quite so good. There is always a little risk in making experiments with the sender too near the receiving instrument, because electro-magnetic effects are apt to come in. I noticed this when working at first from one end of the laboratory to the other. The core of the induction coil, I found, would make sufficient stray magnetism to work the thing.

I will say, as regards the sensitiveness of this particular instrument, that it would seem as if a mechanical device ought to be better than the coherer, for this reason—we can make a galvanometer which will work with a current of about 10^{-11} amperes and a resistance of about 100 ohms or less. That makes about 10^{-20} watts or 10^{-13} ergs per second. I do not think that you can make a coherer work much under a fraction of a volt. What is the smallest that you have succeeded with, Mr. Clark?

Mr. Clark:—I have not experimented in that line at all.

Prof. Fessenden:—I do not think you can make it to work very much under a volt; that is of excessive voltage above the regular voltage of the battery, and in that case, roughly taking the quantity of electricity as equal to the smallest amount possible, that is to say, enough to charge it electrostatically, which would make its capacity about unity, we find you would get about five millionths of an erg. Now reducing ten seconds period down to a tenth of a second, you find the galvanometer should

be about ten thousand times as sensitive. Of course you won't get this; but it seems to show there is some hope that way[1]

Dr. M. I. Pupin:—I would like to ask Mr. Clark why he did not clean the balls. When he said he worked with dirty balls, it seemed to me it was a very small matter to clean the balls. Why didn't he clean them? Was it on purpose or accidentally?

Mr. Clark:—I did not clean them because Mr. Marconi said to me that he found better results at the present time with rough balls than with smooth ones, and that rather tended to confirm the results of some of my own experiments.

If I may be permitted I would like to ask one more question. I do not profess to be a theoretical man. I am working entirely on practical lines, and perhaps some of you this evening, perhaps Prof. Fessenden, can set me straight on one or two points. Prof. Fessenden mentioned that he was able to get transmission across the room by means of the core of the coil. My question to him may not seem a very bright one, and if so I ask it in ignorance. Why is it then that if we take a very powerful magnet and bring it in the neighborhood of the coherer and move it around all that we please, we cannot affect the coherer in any way.

Prof. Fessenden:—I think that the reason of that would be that when the interrupter breaks the circuit the iron demagnetizes in about the ten-thousandth part of a second, or something of that sort, and you would have to agitate yourself very vigorously in order to get equal results.

Dr. Pupin:—What was the spark-length that Mr. Marconi had?

Mr. Clark:—One inch—about two centimetres.

Mr. F. V. Henshaw:—I would like to be enlightened a little bit on the spark-gap question. I had an impression that we had some good rules to go by in regard to proper height of pole and length of spark-gaps, etc.; that if you wish to transmit a long way, you should have a long spark, and if you want to transmit a short way, you should have a short spark. Now it appears that the length of the spark doesn't make any difference, and later on we learn that we can do it all right with no spark at all.

1. Note B. The original instrument described can be used for receiving signals up to 5 miles with a 20-foot pole and 5-inch spark, even without the use of condensers. A slight change recently made, has increased the sensitiveness about 40 times, still without the use of condensers or tuning. For those who may wish to experiment in this line, I would say, that the following dimensions will give an instrument much more sensitive than the coherer, and capable of use over long distances. Coils, two in number, 400 turns of No. 32 wire, boiled in paraffin. Coils $\frac{1}{3}$ inch inside diameter and $\frac{1}{8}$ inch long. Moveable ring, No 26 wire, $\frac{1}{2}$ inch diameter, mirror $\frac{1}{4}$ inch diameter.

Where great sensitiveness is required, use smaller coils and ring of silver with a scrap of silvered glass, very thin and $\frac{1}{16}$ inch diameter fastened to ring. Observe motion by reflected spot of light from glass. A silvered film of mica or celluloid might be used where great dampening is desired.

It may be of interest to mention that in sending signals across $1\frac{1}{2}$ miles of city buildings, diagonally across blocks, the signals were only about 10 per cent. of what they would have been over free space.

If there are any quantitative results with regard to the ratio of the spark-length to the other factors, I think it would be very interesting to have them.

Prof. Fessenden:—I have just given my measurements on the relation between the length of spark and the effect at the receiving end. I pointed out that the effect at the receiving end did not quite vary as the square of the spark-length. So that in doubling the spark-length you do not get quite four times the effect, as you should.

Mr. Henshaw:—Then there must have been something in Mr. Clark's results that masked that. Didn't I understand you to say that you got better results with a one-sixteenth inch spark than with a long spark?

Mr. Clark:—Yes, for a short distance, and Prof. Fessenden explained how that occurred. He has experimented to a greater extent in that line than I have. But Mr. Marconi has transmitted 110 miles with a one-inch spark, and he uses a one-inch spark from five to ten miles, just the same. In fact, he has adopted a spark of that length as a standard.

Mr. C. E. Dunn:—Mr. Clark, I believe, said a few moments ago that he found that he got results without any spark at all. I would like to ask him if he had any idea from what the effect arose.

Mr. Clark:—I do not claim to give any reason for it at all. I simply state the fact. Prof. Fessenden, as you have heard, states that he thinks it was due to the magnetic influence from the core of the coil. But I have tried the action of a very powerful magnet in the neighborhood of a coherer, and making and breaking the circuit of that magnet with a vibrator, placed at a safe distance, I have found no results. But in case any of you may be experimenting with the interrupter of your coil in a vacuum, I want to tell you something that happened at the exhibition over in Boston. We were blowing up a boat every day, four times a day, by wireless telegraphy from across the hall, and we found, to our astonishment, that at about two o'clock each day something interfered with us, and we consequently had to blow up the boat a few minutes before two. Now, Mr. D. McFarlan Moore had his artificial daylight down in the basement, several hundred feet away from us, and we found that he started up about two o'clock, and after a little experimenting we found that we got these waves from Mr. Moore's apparatus. You all know that his interrupter is in a vacuum, and we could not find any sparking or anything that we thought would influence our receiver, except the sparking in the vacuum; so after that we claimed to blow the boat up by artificial daylight.

Dr. Pupin:—In reference to getting the effect without the spark, I think I was the first to show Mr. Clark that under certain conditions it could be obtained. Mr. Clark, two or three years ago, showed his apparatus to the New York Electrical

Society. I was its president then, and heard Mr. Clark's lecture. I tried the apparatus that Mr. Clark showed, and I saw that it would work whether the interruption of the primary current produced a spark or not. I think Mr. Clark was very much surprised that such was the case. Of course, the distance was the length of a table, and the receiving line was connected to a water pipe, and the transmitting line was connected to the same water pipe, so it was equivalent to having the receiving and transmitting line connected, being one line, of course, and as soon as the primary was broken, of course the transmitting line as well as the receiving line was charged, and that charge produced a spark in the coherer and made it operate. It is, of course, not necessary for a short distance like that to have a spark at all. But, if you take 100 yards distance, I am perfectly sure you could not get any effects at all unless you have a spark.

Mr. Clark:—On the occasion which Dr. Pupin mentions, one wire was connected to the water pipe, and the other to the gas pipe—at least, I supposed that was the case. But I found, to my delight the next morning, that our man had not carried out his instructions, and the transmitter was not connected to a ground at all. At the present time, with the instruments that we are now using, I find no difficulty at all in transmitting 30, 40 or 50 feet with only a perpendicular wire of about eight or ten feet in height, with no ground connection whatever, which of course is very much more interesting. I have also succeeded in directing the movements of a model automobile, quite a large-sized piece of apparatus, weighing about 50 pounds, with no trouble at all.

The President:—Was that with a spark?

Mr. Clark:—Yes, with a spark.

The President:—If there is no further discussion, I think that we ought to extend a vote of thanks to Prof. Fessenden and to Mr. Clark for their entertaining descriptions. The subject is an extremely fascinating one, fraught, perhaps, with many possibilities in the future, and the discrepancies which are bound to occur between the evidences of practice and the prophecies of theory are only the more interesting, since they show the great complexity of this subject and the many facts which enter into each case. But, no doubt, as we get more experience on the one hand, as we acquire better apparatus on the other, and as we also get more and more insight into the nature of the phenomena which are involved, we ought to be able to bring theory and practice into a more complete degree of uniformity.

Dr. Pupin:—I was invited to take part in this discussion, and I came to discuss the subject, but I would not carry out my resolution, if I did not think that we have not yet touched upon the possibilities of wireless telegraphy. So far we have had an exchange of personal experiences. These experiences are all very interesting, and I am sure that we are very much obliged to

Prof. Fessenden and to Mr. Clark for their very valuable information. It is extremely important that we should know from actual personal experiences what are the difficulties involved in wireless telegraphy. But the subject of this evening is "*the possibilities of wireless telegraphy*," and I do not think that the AMERICAN INSTITUTE should adjourn without saying something relative to these possibilities. Of course when a man speaks about the possibilities of anything, it is all in the future, and he has poetical license—he can indulge to his heart's content. Now, if you will allow me to indulge a little bit, I will tell you something about what I think might be the possibilities of wireless telegraphy. My ideas on the subject are not an offhand notion. I have thought a great deal about the subject. I teach in a college; am called upon quite frequently by young students to tell them something about wireless telegraphy, and if I go out into society or among business men, and they know that I am a professor at a college, they think that I know all about wireless telegraphy; so they come to me and ask me all about it, and of course I try to give them an intelligent answer. So, whether I want to or not, I have to think a great deal about it. It is in the line of my business. If I make a mistake in my figures, or if I should be a little too sanguine in my expectations, you will be very indulgent with me, because I am speaking about mere possibilities.

One of the possibilities is the tuning of receiving apparatus. The chief difficulty to-day is that if two transmitting stations are working at the same time, the message received at the receiving apparatus is unintelligible, because they interfere with each other. It is, therefore, very desirable that the receiving apparatus should be tuned so that it will respond to one transmitting apparatus only, and to no other. The second important point is that we should extend the distance as much as possible. These are the two important points, and I think the possibilities in those two directions are very great.

Now, if you will allow me to go to the blackboard, I shall try by diagrams to make myself clearer than I might otherwise do. The evening is still young, and we have lots of time; so don't get impatient. In case you want to go, why do so, I won't feel offended.

The transmitting wire as it is constructed to-day consists of a long vertical wire, *a b*, Fig. 5, and a spark gap *a c*, and an earth connection G, and the receiving wire is *e d*, the coherer is at *f*, and the local circuit *g f h*, the induction coil A, is also indicated connecting to the two sides *a c* of the spark-gap. I would like here to ask Mr. Clark a question. How many breaks per second did Mr. Marconi employ:

MR. CLARK:—I cannot answer that question definitely. He had a very rapid rate, the most rapid one that I have heard. I can only guide by the ear.

Dr. Pupin :—The fastest mercury break used with induction coils that I have seen, did not go very much over thirty a second.

Mr. Clark :—Mr. Marconi said that all he required for dots was one spark between the balls.

Dr. Pupin :—That is not the point, though, that I wanted to know.

Prof. Fessenden :—You can call it 500 per minute possibly. When it gives a high pitched note, it would be somewhere around there.

Dr. Pupin :—That is about 8 per second. When you excite two wires like *a b* and *c* G until the potential is high enough to make the spark in the spark-gap, then each spark is followed by a series of oscillations. They are the so-called free oscillations of this wire—the wire *b a c* G. The wave-length will depend

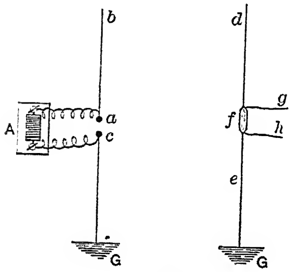


Fig. 5.

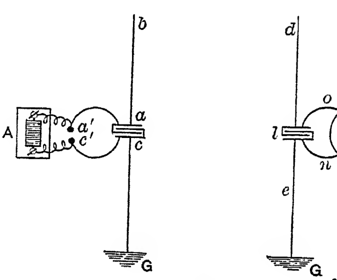


Fig. 6.

on the nature of the excitation. I do not care to go very deeply into that for two reasons—because I don't know much about it, and secondly, it is not necessary—two very good reasons. I will tell you why it is not necessary, and why I do not know much about it. Take a wire like *b* G, the capacity of which is a variable quantity, because the capacity of any element depends on its length and its distance from the earth. As you go up along the wire the capacity of the wire is continually diminishing. The free vibrations of a wire like that, are like the free vibration of a string, the elasticity of which varies from point to point. Now, no man on earth would be able to tell you with any degree of exactness what sort of oscillations you would get there. I don't think you would get a pure harmonic oscillation. There will be an oscillation of all sorts of unrelated frequencies. If we had an ordinary wire where the capacity per unit length is a constant quantity from beginning to end, the problem is very easy; it has been solved; the wave-length that the wire emits is a multiple of the length of the wire. Prof. Fessenden told us that the wave-length is about four times the length of the wire. Now, these oscillations are very much

dampened, for this reason—that you have a great deal of dissipation of energy right in this spark-gap. If you could excite *oscillations in a wire without a spark-gap*, these oscillations would have some damping, but not very much. They would be, so to speak, sonorous oscillations, as when you strike a bell made of fine bell-metal, it continues to ring for a long time after the stroke is delivered. But if you put a finger on the bell and strike it then, or put in some resistance, the sound dies out very rapidly. So that is the state of affairs in this transmitting wire with a spark-gap. You have the high resistance, dissipation of energy, and the oscillation is a very damped one; you have only a very few waves sent out after each spark. Now, when you have a train consisting of very few rapidly diminishing waves, they cannot produce much resonance.

That is the reason why they have not been able to tune their receiving apparatus in England, that is, I think so. I don't know anything in this line for certain. I know only one fact, and that is that nobody has been able to tune the receiving circuit. What I mean by tuning is this: if the receiving wire has the same period as the transmitting wire, then the wave coming from the transmitting wire will excite strong oscillations in the receiving wire under proper conditions; but if the receiving wire has not the same period as the transmitting wire, then the oscillations induced in it will be small. Now, even if the two are in unison, and the transmitting wire sends only a few rapidly decaying oscillations at stated long intervals, then you will get no appreciable resonance. To produce strong resonance you must send forth oscillations which have little damping. That has been shown experimentally in the case of the Hertzian oscillations, and these are, in a certain sense, like Hertzian oscillations, because they are of high frequency. Hertz showed that if you have a series of slowly decaying waves, and they strike a conductor having the same periodicity as the conductor from which these waves proceed, you then get very strong resonance effects Here is another method of producing strong resonance effects. If you produce a series of rapidly decaying waves, you will get small resonance, but this small resonance effect would be magnified if you could repeat these dampened impulses at very quick intervals. Instead of having eight sparks per second, suppose you had one hundred thousand sparks per second, each succeeding train of rapidly decaying waves will strengthen the effect of the preceding train. Then the current here in the tuned receiving circuit would swell up, and ultimately you will get a very large resonant oscillation by a sort of accumulative effect. So that in the present method of wireless telegraphy, we are laboring under two difficulties: one difficulty is that the waves proceeding from the transmitting wire are very much damped. The second difficulty is that the sparks do not proceed in a sufficiently rapid succession. Eight sparks per second—that is

nothing at all, it is the coarsest kind of dilettante work. It may be good enough for the present, but it is not enough for the possibilities of the future. If we are to speak about possibilities of the future, then it seems to me we ought to consider these two points: One is to produce electrical oscillation in this transmitting end, which are less damped; secondly, to produce a much more rapid succession of sparks, a much more rapid succession of impulses. Now, I am going to tell you one way that I think would operate and be successful in transmitting less dampened oscillations. I shall describe a method which I have tried, in connection with another scheme, for which there there are several claimants besides myself. Suppose we have a wire *a b c* G (Fig. 6) and a condenser *a c*. Suppose that the condenser plates have a shunt with a gap a^1 c^1. Connect the induction coil with the two sides of this spark-gap. This is a condenser having a considerably larger capacity than the capacity of the vertical wire, and it is preferable that the shunt wire have considerable self-inductance. This arrangement represents exactly the following mechanical analogy. In Fig. 7, A B C is a tuning fork, with its neck, C, rigidly fixed, and a string, A D, attached to it. One end, D, of the string is fastened. Suppose you strike this tuning fork, it will vibrate and make the string vibrate, and the vibration of the string will continue as long as the tuning fork vibrates. If the tuning fork is heavy, its vibrations will continue for a long time after each stroke. The string performs forced vibrations, and not natural vibrations, which it would perform if it were fastened at its terminals and then struck. The forced oscillations of the string are not rapidly decaying, because the body vibrating it—the tuning fork—is a sonorous body. The condenser, *a c* (Fig. 6), with a shunt, is an electrical oscillator, an electrical tuning fork. The Hertzian oscillator is an electrical tuning fork. The analogy is perfect. It is not a mere superficial analogy; it is a perfect analogy. Every time you pass a spark, that is equivalent to giving the tuning fork a stroke. You start oscillations in this circuit just as you start the vibrations of the tuning fork by a stroke. These oscillations then keep up the oscillations in the vertical wire. Oscillations like that have been produced by Hertz himself. The wire was not connected to the earth, to be sure, but that does not make a very essential difference. I will give you an illustration of one Hertzian arrangement which is very interesting. It is represented in Fig. 8. A, is the induction coil, B C D E are four plates 16 in. square, and at a distance of 4 in., and *a b* is the spark-gap and E H and D K are two long wires with bridge, F G. The circuit, C B E F G D C, is the oscillator, the electrical tuning fork; the wires, E H and G K, are the electrical strings vibrated by the electrical tuning fork. This arrangement, the so-called Lecher arrangement adopted by Hertz, gives electrical oscillations, when the spark-gap is small, which are very sonorous.

After each spark a long series of waves will be emitted from a system like this. I don't care where these waves go, a part of them will certainly strike the receiving wire and will continue working there for some time. Now all you have to do at the receiving wire is to have another electrical tuning fork synchronized with that at the receiving end. Such an arrangement is given in Fig. 6. The condenser *l* with its shunt *o m n* is the resonator. By varying the dimensions of the shunt *m n o* or the capacity of condenser *l* we can tune this circuit. I do not see why such a circuit should not resonate. I would like some one to tell me why it should not. It does it in the ordinary conditions in the Hertzian experiments. I do not see why it should not do it here. There is nothing mysterious or even strange about these waves employed in wireless telegraphy, they being perfectly simple waves like any other electrical waves and can be made to obey the same rules. Now the receiving resonator will be even more sonorous, a great deal more sonorous than the transmitting oscillator. Two circuits may have the same period but different decrements. Two bells may sound the same note,

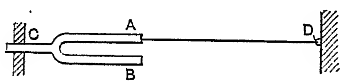


FIG. 7.

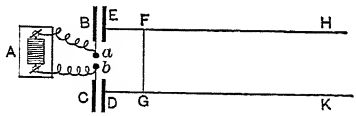


FIG. 8.

but one will continue for a long while to ring and the other may die out very shortly, depending on the internal friction and depending on the material from which the bell is made. The receiving resonator will have the same period as the transmitting oscillator when they are in unison, but the first one will have a larger decrement. That is because its frictional losses are larger. The coherer, *f* is, of course, supposed to be in a secondary winding as shown in Fig. 5. The oscillations once started in the receiving resonator will continue a much longer time than those in the transmitting oscillator. Now that is a very important point. Prof. Fessenden has told us that these oscillations are about three millions per second. I think he is very near the truth. They are considerably slower than the Hertzian oscillations on account of the length of the transmitting wire. Now these oscillations, excited by a resonator like the one in Fig. 6 are very persistent. Five thousand wave lengths, that is five thousand complete oscillations, will be emitted. Oscillations will take place before the resonator becomes exhausted. The oscillations in the oscillator are not so persistent on account of the air-gap. Say 500 oscillations take place after each spark before the oscillator is exhausted. That is, for five hundred three-millionths of a second, or for five thirty-thousandths or for one six-thousandth of a second,

these oscillations will persist after each spark, and then the electrical tuning fork is ready again to be struck again by an electrical blow, by a spark. You see that this oscillator is a tuning fork, that you cannot strike before the oscillations have subsided, because the air-gap conducts too well while the oscillations are going on. On account of the air-gap you have to wait until the oscillations die out before the induction coil can produce another spark. So that only after one six-thousandth of a second the oscillator will be ready to receive another spark. Now, the receiving resonator will continue considerably longer, there being much less damping. That is, after one six-thousandth part of a second, after the last wave-length is reached here the induced oscillations will continue for a considerably longer time, say ten times as long; that is, one six-thousandth of a second, plus ten six-thousandths of a second. This is of course very rough. I do not pretend to great accuracy. I only wish to make my meaning clear, and to illustrate it by a numerical example. One six-thousandth plus ten six-thousandths—well, make it twelve six-thousandths per second, which is one five-hundredth of a second. You see, the oscillations in the receiving resonator will continue for one five-hundredth of a second after the first spark in the transmitting oscillator. Now, suppose that you pass a spark every thousandth of a second. You see, then, that when the second spark takes place, and the wave-train sent out by this spark begins to arrive at the receiving end, the oscillations there have not died out yet by one five-hundredth of a second; there is still wave-energy left at the receiving end. Now, the second spark will add more wave-energy to the receiving resonator, the third still more, and so on. There will be an accumulative effect in the receiving resonator. It is just like having two tuning forks that are tuned to each other. Strike one tuning fork the second will resonate to some extent. Then, before the energy which the second tuning fork has received, has decayed, if you strike the first tuning fork again and again, the resonance of the second tuning fork will continually increase until it reaches a maximum effect, and you cannot go beyond that. That may be called the accumulated effect of resonance. You see, then, the utility of numerous sparks rapidly succeeding each other; I think a thousand per second is none too much. Well, the scheme would operate all right if you could do all these things. But here are the difficulties, and this brings us to the second point of my discussion. I have made a short calculation, using for the condenser capacity at the transmitting end about two-hundredths of a microfarad. That, is, the condenser plates are about a meter in length, and they are at a distance of one centimetre, and using a spark-gap of a quarter of an inch, requiring ten thousand volts, roughly. The coil will have to supply a kilowatt to the electrical tuning fork at the transmitting end, and a very large fraction of that kilowatt is used up in this spark-gap, because an elec-

tric radiator is not very much more efficient than an ordinary radiator; a great deal of it goes into heat. I think the efficiency is just about as bad, if not worse; so that perhaps 95% of that kilowatt would be used up in the spark-gap, and the rest is radiated into space, a very small fraction of which operates the receiving apparatus. What do you think becomes of the spark-gap spheres if the heat generated there is not carried off? They will be dirtier than the balls of Mr. Clark's instrument. I think that in less than no time they will be fused, and you won't be able to get any spark through them. There is the difficulty. The rest of that I leave for you to solve. We must put a great deal of energy into our transmitter in order to increase our distance of transmission. The more energy you put into any radiator, I don't care what it is, the better illumination you get. The more energy you can get into an electrical radiator, the more energy you can get out of it, the longer the distance over which you can transmit a certain amount of energy. There is not the slightest doubt about that. What we want, then, is, in the first place, to be able to put a great deal of energy into our radiators; secondly, very rapid succession of sparks; thirdly, radiators and receivers of small damping, and as a result of all these things, an efficient tuning of the receiving to the transmitting apparatus. The solution of these problems will increase the sphere of future possibilities of wireless telegraphy more than anything else that I know of.

THE PRESIDENT:—Is there any further discussion?

MR. CHARLES P. STEINMETZ:—I only want to add that I should not be afraid to dissipate even more kilowatts between a pair of balls. I think the best way would be turn a stream of high pressure air blast on it. You have no idea of the enormous amount of energy you can carry away in an ordinary air blast, twenty to thirty pounds pressure to the square inch. I had experience with that. I had occasion once to dissipate a considerable amount of energy between a pair of balls which I used in a high-frequency condenser charge.

MR. C. O. MAILLOUX:—I would like to ask Dr. Pupin if he would not be likely to have an additional difficulty in the synchronizing of his set of waves, which it seems to me would be essential for obtaining cumulative effects by resonance. When he starts a set of waves and gets resonance at the other end, the resonance can be kept up and increased only if the succeeding wave is in phase with the preceding one. It seems to me that we have to synchronize with the second set, and with all the sets succeeding each other, because otherwise it would be like vibrating a string, and then trying to vibrate it again in some different phase. Taking Dr. Pupin's example of the two tuning forks, if he struck the first tuning fork anew too soon or too late, or if he did not strike it at a certain critical time, or in the same phase of vibration, it seems to me the effect would be that the second fork

must synchronize anew, and hence I should think there would not be any cumulative effect in the resonance. Each wave would have only its own resonance.

DR. PUPIN:—No, there is no interference. Wave-energy is superpositive. The transmitting apparatus sends waves of the same period all the time. You can put them anywhere you please. There is no interference.

MR. MAILLOUX:—Do they accommodate themselves by mutual induction—the inductance effect or electrostatic effect?

DR. PUPIN:—Do you mean to say that when I sing ah, ah, ah, I synchronize the emission of my sounds, and that unless I do that you won't hear me? It is the same thing.

[Adjourned.]

DISCUSSION AT CHICAGO.

OPENED BY MR. ARTHUR V. ABBOTT.

MR. ABBOTT—Mr. Secretary and Gentlemen: If my understanding is correct, Mr. Marconi came over to this country to aid in reporting the recent yacht races, and it was expected that he would give the INSTITUTE in New York a description of the art that he has so successfully brought to a practical basis. Mr. Marconi had to leave this country sooner than was expected, and was unable to present his paper. We are, therefore, about to discuss a subject we have never listened to. Before, however, we can consider any topic with profit, it is desirable to know something about it; and I will take a little time to recall some principles, probably seeming to many of you elementary, but which appear to me to be desirable to have prominently in mind.

All modern inventions and discoveries are based upon new applications in the utilization of energy. We do not find out new *things*, and we make very few new material combinations. But what the nineteenth century is remarkable for, is the discoveries, the inventions, the applications, the utilizations of the various forms of that which we now term energy.

It is but 200 years ago that heat was supposed to be a material substance. Newton thought that light was an essence; a something emitted by each shining body. And it is barely fifty years since Joule and Mayer demonstrated the mechanical equivalent of heat and work. So, one after another, sound, heat and light have been shown to be (as Prof. Tyndall so aptly described them), modes of motion, or forms of that something which we call energy, and which, in its essence, is as yet to us totally incomprehensible, totally unknown. All that we know of it is that in conjunction with matter, certain phenomena, certain results appear, that we term manifestations of energy.

At the beginning of the century, Franklin explained electricity on the hypothesis that it was material substance. He asserted that a positively electrified body contained more of a certain kind of fluid, and a negatively electrified body less. We can see how that idea yet remains, because at present we talk of currents and flows; we speak of electricity as running. But there isn't any flow; there isn't anything in the material sense of the word. Electricity is no more a substance than the light from an incandescent lamp. So we are now revising our ideas of electricity in exactly the same way that Young, and Joule, and Tyndall revised former notions regarding heat and light.

Twenty-five years ago Maxwell predicted that electricity would be found to be a kindred manifestation to the other then known forms of energy. We at the present time are not positive that electricity is a mode of motion. We are not quite sure of that. But I think that the evidence is strongly in favor of this view. On the other hand, some scientists speak of electricity as if it were identical with ether, stating that as it manifests properties similar to inertia, that it must be a substance. In reality this is only a talk about words. We never talk of heat as substance, but there is no doubt that heat is an ether manifestation. We never talk of light as a substance; but light is undoubtedly an ethereal manifestation. In each case the ether is the road, or means of communication whereby an energy manifestation taking place at one point may travel through space. But the ether is no more energy than the railway track is the locomotive that runs over it. So, in the future the scientific world will probably regard electricity from the same standpoint that we now consider light, as etheric manifestations.

Maxwell, twenty-five years ago, with a mathematical insight that has never been equaled, gave certain equations, expressing in symbols all of the electrical phenomena with which we are now acquainted, and by means of which we are able to correlate electricity and light in such a way as almost to show that the quintuple group, light, heat, electricity, chemical action, and possibly the attraction of gravitation itself, is a vast chain in which each form is a link in the circle that brings every exhibtion of energy back to its origin in motion.

Ten years ago Prof. Hertz, in Berlin—one of the most patient, one of the most careful, one of the most astute investigators that the world has ever seen, took up the problem of demonstrating experimentally some of the conclusions that Maxwell had shown algebraically.

Hertz's classic experiment, which I have assumed to be so familiar to you as to be unnecessary to present, consisted in taking two circles or rectangles of wire, one of which was connected to any source of electricity, such as a Holtz machine or an induction coil, and showing that when one circuit was properly related to

the other in its various electrical properties, an electrical disturbance set up in the first circuit would be followed by a corresponding electrical manifestation in the second circuit, even though the two were separated by a considerable space, thus proving that the electrification in the second was due to a wave action between the first and second, and that the second operated merely as a receiver. Hertz's discovery was a physical proof of the existence of the waves Maxwell had predicted, and as soon as Hertz's demonstration was placed before the scientific world it was immediately seen that if by any means it were possible to detect electric waves, it would be an easy matter to transmit intelligence from one point to another, over the highway of the luminiferous ether.

For if by any means we can excite electrical vibrations at one point, and can catch these vibrations at another point, it is simple to devise a code whereby the waves emitted at one point may be caused to convey intelligence to another. The synchronic circuits of Prof. Hertz were so insensitive in their ability to report the existence of electric waves, that it was impossible to show the presence of such oscillation more than a few feet away from the emitting apparatus. If I recollect rightly, Hertz's Memoirs do not describe any successful experiments over a distance greater than that occupied by a large room, say 50 or 100 feet. But Hertz also showed the possibility of reflecting these waves, or of refracting them, and of polarizing them, demonstrating that they followed and exactly corresponded to all that we know of all other forms of radiant energy.

In 1891 or 1892 Prof. Branley discovered that under certain circumstances a metallic powder become very sensitive to electrical radiation. He found that ordinarily a metallic powder, such as a heap of filings, offered a great resistance to the passage (now I have to go back to the old-fashioned word) of an electric current. If the two poles of a battery are dipped in metallic filings, no sensible current flows, as may be shown by a sensitive galvanometer. But if an electric wave, if the radiation from an induction coil or similar apparatus impinges upon these filings, a very curious change takes place, and the resistance formerly measurable in megohms, drops to a few hundred ohms or less. The filings offer, therefore, a means of detecting the presence of electrical radiation far more delicate than is yet found in any other way. They are the mechanical spectacles whereby the presence of electric waves can be made apparent to the eye of the brain. We are made acquainted with our environments solely through certain sets of nerves. Imagine a man deaf, blind and sensationless, what could he know about the world? Absolutely nothing. He could not hear, he could not see, he could not feel. Now through these three channels, and these only, we come into contact with the environments, and we translate to ourselves all the phenomena that take place around us,

and it is obvious that if there are any such phenomena which do not appeal to some one set of nerves, we are absolutely oblivious of it.

Standing on the top of a mountain, looking down into the valley below, one is insensible to what the eagle flying near one's head sees, because our eyes are not as acute as his. On the plains with the Indians, one does not perceive a thousand things that they instantly cognize. And why? Because our senses and our attention are not trained in the same direction as theirs. It is often said, that the modern eye is deteriorating. Here is the Indian; he can see a man five miles off. True, but the optician can make one see a man fifty miles off, because he can give a telescope; and on the whole I would rather have the telescope and my eye, than the Indian's eye without the telescope. A man can hear another shouting a few hundred feet away; but I would rather have a telephone and listen to New York. So we are constantly adding to, and increasing our perceptive limits, by means of mechanical appliances.

So the filings in the little tube, which has now been denominated a coherer, is a new mechanical appliance which enables us to penetrate into regions of space, which have previously been barred to us; which, so far as we are concerned, were empty. The magnetic waves from the sun at every eruption of hydrogen have radiated outward through space, enveloping the world and sweeping around it in the same way that billows of the sea engulf the grains of sand on the shore, and man has been utterly oblivious thereto; but every magnetic needle has trembled with every hydrogen eruption. The coherer is as yet insensitive to the radiation from the sun, but we certainly can detect that from the lightning flash. So Professor Branley in that way has furnished us with another mechanical device for penetrating into the fields of radiant energy that surround us, in a way hitherto unknown.

Now I am going to request the lights to be lowered, so that we may consider more definitely what is known about radiant energy.

TABLE No. I.

Waves in the Air.
Sound Speed, 1,100 Ft. per Second.

	No 1. DESIGNATION.	No. 2. Wave-Length.	No. 3. No. of Vibrations prr second
Eleven Octaves.	Visible Motion......		Less than 16
	Lowest Audible Sound.....	68 ft.	16
	Lowest Musical Note	34 "	32
	Man's Voice.......................	8½ "	128
	Woman's Voice	4½ to 2⅛ ft.	256 to 512
	Highest Soprano	0 ins.	2000
	Highest Musical Note	3 ins.	4000
	Highest Audible Note......	¼ in.	40000

The first table which I place upon the screen (See Table I) is a list showing us what the senses can gather from the slowest vibrations of an oscillating body. We are all pretty familiar with this form of wave motion, so I dwell on it but for a moment; just to call to your mind, that visible motion is something less than 16 per second. The lowest audible sound is about 16 per second, with a wave-length of about 68 feet; and the highest audible sound has a wave-length of a quarter of an inch, with about 40,000 vibrations per second. This table shows the group of waves which appeal to one set of nerves, the aural nerves; below 16 the ear refuses to recognize any vibration, and above 40,000 per second, the ear fails to hear.

TABLE II.

Waves in the Ether.

Heat and Light Speed, 186,000 Miles per Second.

	No. 1. DESIGNATION.	No. 2. Wave-Length.	No. 3. No of Vibrations per second
Heat Waves 4 Octaves	Lowest Heat Sensation	583 millionths of an inch.	20 trillions
	Highest Heat Sensation......	392 ten " " "	300 "
Light Waves 1½ Octaves	Red Light....	271 " " " "	434 "
	Orange Light	258 " " " "	500 "
	Yellow Light	244 " " " "	520 "
	Green Light...	207 " " " "	570 "
	Blue Light	191 " " " "	634 "
	Indigo......	169 " " " "	680 "
	Violet Light............. .	165 " " " "	740 "
	Ultra Violet Radiation.	140 to 85 ten millionths of an inch.	870 to 1500 trillion
	Roentgen Rays........	Unknown.	Probably 300 quadrillions.

Now in Table No. II., we consider the next group of waves that the senses cognize. The ear can perceive vibrations from about 16 to 40,000; but from forty thousand up to twenty trillions per second there is no set of nerves that responds, and so far as we are concerned space is empty. But there is a large group of insects that probably have faculties, nervous systems, brain organizations, that enable them to recognize at least something of what takes place in that gap. Whether we shall ever develop any faculties of that kind is problematical, and so for the present at least, we must seek mechanical appliances to penetrate this region. From 20 trillions to 300 trillions the nerves in our skin, respond, and we say that we feel a sensation that we call heat. With the sound waves we hear through a range of eleven octaves. Heat waves we feel only through about four octaves. The heat scale resembles the sound scale, and with the

proper instruments we may analyze this group of waves from 20 trillions to 300 trillions, and construct a thermal scale, corresponding to the audible scale.

Between 300 trillions, and 430 trillions, there is another gap at present, imperceptible to our senses, but at 434 trillions the eye takes up the analysis, and the retina translates to the brain the waves which impinge thereon, and we can see vibrations from 434 trillions to 740 trillions, giving a chromatic scale,— not chromatic in the musical sense, but chromatic in the color sense,— for the different rates of vibration are recognized as different colors. For there is absolutely no difference between a ray of red light and a ray of violet light, save in rapidity and in wave-length.

Beyond the end of the visible spectrum, photography shows us that radiation persists with ever-increasing rapidities, until we reach about 1500 trillions per second; then photography fails. But Professor Roentgen a few years ago showed us that the end was not yet, and there were still other fields, still other regions, in which vibratory energy increases in rapidity to an inconceivable extent; for when the mind attempts to picture a wave motion of 300 quadrillions per second—which we estimate to be the speed of the X-rays—one is in the presence of a number that is absolutely meaningless.

In the gap I spoke of a few minutes ago, between the upper audible limit and the lowest sensation limit, there is a space of about 31 octaves, and in this region the oscillations of electrical radiation upon which wireless telegraphy is based, takes place. This is the region into which we wish to penetrate—by means of the coherer; but we hope in the future to find something a great deal better, a great deal more sensitive than even that instrument. In Table III. I have collected some of the data pertaining to electric waves that may be of interest.

TABLE III.

Waves in the Ether.

Electro-Magnetic Waves, Speed 186,000 Miles per Second.

No. 1. DESIGNATION.	No. 2. Wave-Length.	No. 3. No. of Vibrations per second
Magnetic Waves from the Sun.....	1¼ millions miles	1 in 6½ seconds
Flash of Lightning	11000 miles	17
Induction Coil	18 miles	10000
Pint Leyden Jar..............	54 ft.	18 millions
Large Oscillator	1 ft.	100 "
Five Inch Oscillator......	7 in.	172 "
Shortest Electrical Wave	2½ in.	480 "

Now, leaving the screen, we will see if I can excite some of the electric waves that are pictured in that list. Every electrical circuit has three properties—resistance, inductance and capacity.

The form of radiation obtained from any circuit depends entirely upon the mutual relations of these three electrical properties. Throwing a stone upon the surface of a smooth pond, excites a ring of waves that extends from the center of impact to the margin of the water.

Now, if we imagine the luminiferous ether—in which all of the known universe is supposed to be immersed—to be a spherical pond, and if we can imagine any means whereby we can throw stones into the ocean of ether and make splashes, we can obtain waves. This is exactly what we do in any electrical disturbance.

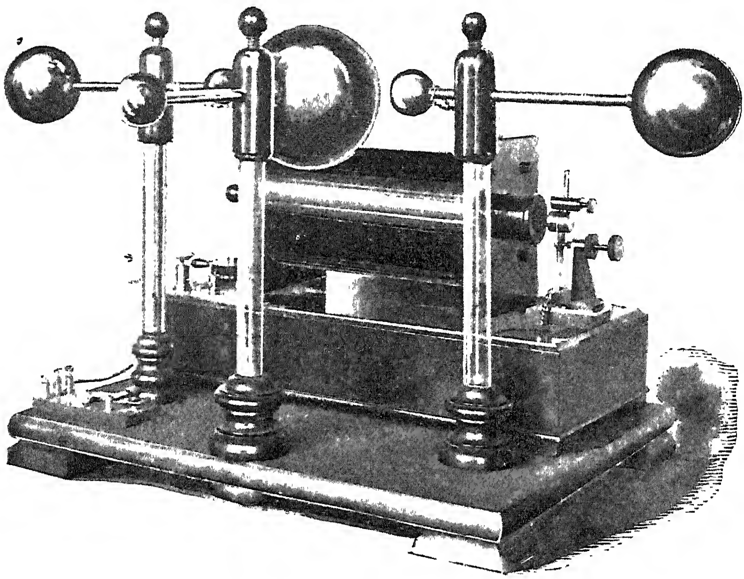


FIG. 9.—Spark Coil Arranged as an Oscillator.

On the table before us is an ordinary 6-inch induction coil. There is nothing remarkable about it, excepting that the terminals are furnished with brass spheres. If the coil is connected with a battery, by touching a key I can send a series of sparks between the termini. That coil is the electrical stone, and the spark is the splash in the ether, the concussion of which sets up oscillations that radiate outward in the form of an electrical wave. [See Fig. 9.]

Let us examine what happens in the case of the induction coil. Suppose there is an increased quantity of electricity on one pole of the coil, the positive, and a decreased quantity of electricity on the opposite side. Whether we regard electricity as a material substance, or if we regard it as ether, this hypo-

thesis remains equally true. If the electrical equilibrium be disturbed, there is a strong tendency to return to the original condition; and that tendency may be compared to action of the the attraction of gravitation upon a stone lifted above the surface of the earth. When the stone is on the surface of the earth, both are in equilibrium. But if we lift the stone, we have disturbed the earthly equilibrium; for each attracts the other. By the induction coil we disturb the ether, and that disturbance of equilibrium is followed by stress between the spheres forming the poles, that increases, until the resistance of the intervening space breaks down, and the equilibrium is restored with a crash.

But there is more than that, as the apparatus acts like a pendulum, for when the intervening space breaks down, the electricity, like the bob, swings from one pole to the other, back and forth several times, but with ever and ever decreasing intervals, as the stored energy is gradually dissipated, and the phenomenon ceases.

I say gradually; we talk of the electric spark being as quick as a flash. True, a spark of this kind vibrates about 200 million times in a second; but 200 million times per second is a long time if compared with the Roentgen ray that vibrates 300 quadrillions per second.

The disturbance of electrical equilibrium, caused by a touch upon this key, gives rise to several series of waves, manifesting themselves in a number of different ways. First there is the sound of the spark; that consumes part of the energy. Second, one may feel, if the hand is near it, the heat of the spark; absorbing another portion. Third, the eyes perceive the light of the flash; abstracting more energy. And fourth, by means of the coherer I will show in a moment, that there is still another form radiated through space to which the nervous system is absolutely insensible.

A coherer is an instrument consisting of a little glass tube, provided with two platinum-coated terminals, to which a battery may be attached, and having the space between the terminals filled with filings of metal. I will pass one around for examination. Exactly how the coherer works we do not precisely know; presumably something as follows: Suppose one is standing on the seashore, after a hot, sunshiny day, the sand is loosened, as one readily recognizes, by sinking ankle deep into it. The tide begins to rise, soon a higher wave sweeps over the sandy beach, and, falling back, leaves as a firm plain what a moment before was merely a loose mass of shifting quicksand. That is exactly what we suppose happens in a coherer. [See Fig. 10.]

In the center of this instrument is a pile of filings that are loose, as is the sand on a hot day. Now the electrical wave washes over that loose pile of metallic sand, and acting upon the ultimate molecules or atoms, it compacts them together.

Previously to the impact of the electrical wave the particles of the filings were not in electrical contact. They were separated by spaces; not very great actually, but great molecularly; separated by a sufficient space, so that the energy developed by two or three cells of battery could not cross the gap, and therefore the center of the tube was electrically open. When the electrical wave impinges upon those metallic particles, the gaps that previously existed are broken down, and the current from the battery is immediately established.

In this box are two or three cells of a dry battery, from which wires emerge and terminate in two brass supports, on which the coherer is placed. There is also a bell in the inside circuit. I will short-circuit the coherer. [Bell rings.] You see immediately the bell rings, showing that all that is necessary is to bridge the gap to cause the bell to sound. If I can excite electric waves by the coil that will wash those filings together, the bell ought to ring. [Bell rings.] But the metal-

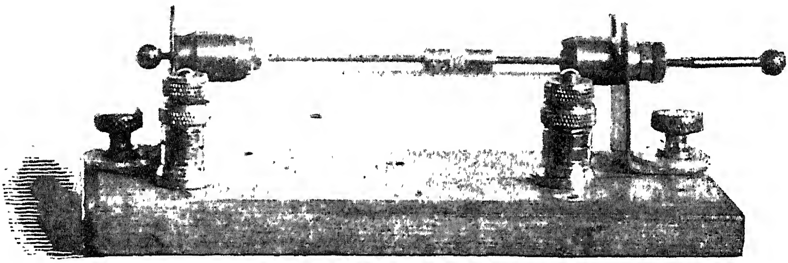


Fig. 10.—Coherer, about Actual Size.

lic sand may be loosened, and should return to its former state of high resistance. Now I will dig the sand up again. I dig it up simply by hitting the tube, and the bell stops ringing. Of course this experiment may be repeated an indefinite number of times. It is simply a physical demonstration of the existence of the waves produced by means of the coil and of their detection by the filings which form the electrical eye, so to speak, that enables us to peer into that space which exists between the upper audible limit and the lower limit of sensation.

To come to some of the possibilities of wireless telegraphy. So far we have had the coherer in open space. What will be the effect of interposing other substances between the coil and coherer. We know that for thermal radiation, rock salt is transparent and glass is opaque; for luminous radiation, glass is transparent, and a brick wall is opaque; for Roentgen radiation a brick wall forms no obstacle. We can literally see through the masonry without the slightest difficulty. It is interesting to as-

certain what is opaque and what is transparent, to electrical radiation.

I will put the bell in a wooden box, and close it tightly. On touching the key the bell rings equally as promptly inside the box as it does outside. Wood is apparently transparent. Let us take another kind of box: here is one of metal. Let us see whether the metal is transparent. [Three trials and the bell fails to ring.] The metal is opaque.

Perhaps I can illustrate forcibly how a lightning rod works. I raise this vertical wire to catch the electrical radiation and bring it into the box, shutting it tight, and touch the key. [The bell rings.] In order to prevent the electrical wave from affecting the coherer we must screen it, not in an air-tight case; as of course this box is not air-tight;—but there must be perfect

FIG. 11.—Coherer Magnified.

metallic continuity around it. But when a wire was extended from the coherer through the case, a portion of the wave traveled down the wire, and influenced the filings. That is exactly the way a lightning rod acts.

I have shown so far, simply the way in which we can generate electrical waves, and the method by which it is possible to detect their presence. It may be interesting to go into the subject a little more technically. Denoting the capacity of a circuit by C, the inductance of the circuit by L and the resistance by R Lord Kelvin shows that if

$$R \text{ is } > \sqrt{\frac{4\,L}{C}}$$

the discharge of the condenser dies away regularly with the lapse of time;

$$\text{if } R < \sqrt{\frac{4\,L}{C}}$$

then the discharge gradually expends itself in a series of isochronous oscillations; the periodic time T of which is given by the following formula:

$$T = \frac{2\pi}{\sqrt{\frac{1}{L\,C} - \frac{R^2}{4\,L^2}}}\ *$$

If R is very small in comparison to the other quantities, as is usually the case in pieces of apparatus designed to emit electric waves.

$$T = 2\pi\sqrt{L\,C}$$

Now as T may be varied by changing either one, or both factors,

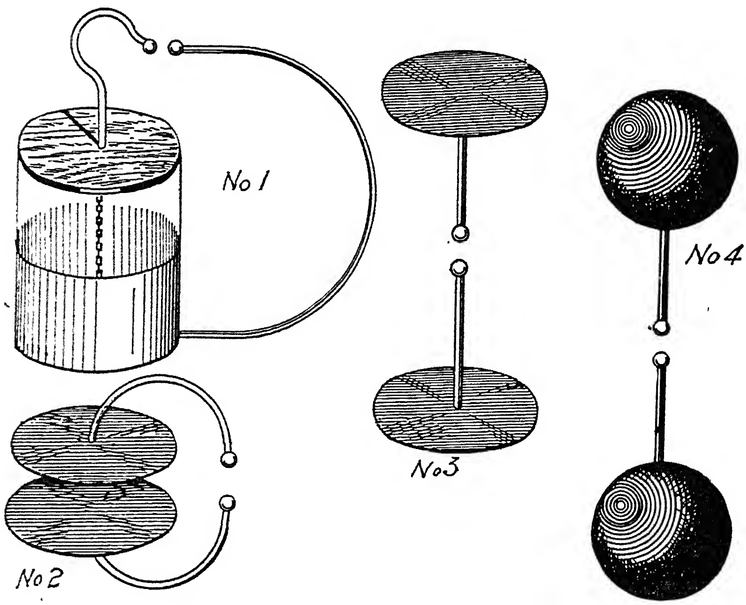


FIG. 12.—The Evolution of the Oscillator.

a very wide range of vibration may be secured, and knowing the periodic time and rate of propagation of the wave, the wave-length is easily found as the quotient of these quantities.

As L and C may be varied through an infinite number of forms, the oscillator, as any apparatus for emitting electric waves is called, may assume a corresponding variety of shapes, but as the familiar Leyden jar is always at hand, the evolution of the present most common spherical radiator is easy to trace, as shown in Fig. 12. No. 1 is evidently a jar with a spark-gap and wire circuit more or less circular in form. In No. 2 the jar coatings have become a pair of plates separated by an air-gap. In No.

* NOTE.—See Lecons sur L' Electricite par E. Gerard, p. 256.

3 the circuit is straightened out and the jar coatings are a pair of disks, while in No. 4, the substitution of spheres for the disk is a natural transition to prevent brush discharge.

In Fig. 13 eight of the most common forms of oscillators are represented diagrammatically. No. 1 is a pair of straight rods terminating in knobs, separated by a short spark-gap. To increase capacity in No. 2, a pair of plates is added to the terminals of the rods. In No. 4 the rods are bent into a ring. No. 3 is a simple sphere, sparked to at either end of a diameter. No. 5 is composed of two equal spheres, the spark-gap placed on a line through their diameters. In No. 6 several spheres are used to produce proportionately greater intensity. While the spherical radiator is exceedingly convenient, it is so dead beat as only to

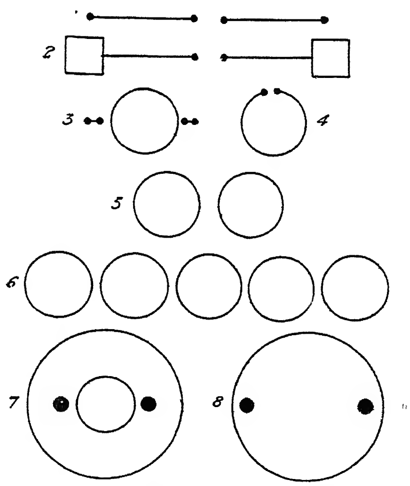


FIG. 13.—Diagram of Oscillators.

give two or three waves. Its vibrations may be prolonged at the sacrifice of intensity by enclosing it in a metal cylinder as shown in No. 7. A similar device is shown in No. 8, composed of a metal cylinder enclosing two spark knobs set on a diameter. For convenience, the formulæ for the wave-length of these forms are appended.

No 1—Two straight rods.

Let l = length of the rods over all, including spark-gap; d = the diameter of the rods, and D = the distance between their centers. Then

$$L = 2\, l\, (\log_e \frac{4\, l}{d} - .75.)$$

in electro-magnetic C. G. S. units.

$$C = \frac{l\,d}{4\,D\,v^2}$$

in electro-magnetic C. G. S. units, when v is the velocity of light.

$$T = 2\,\pi \sqrt{2\,l\left(\log_e \frac{4\,l}{d} - .75\right)\frac{l\,d}{4\,D\,v^2}}$$

If $\lambda =$ the wave-length then $\lambda = v\;T$.

Approximately between the ranges of $l = 10$ cm. and $l = 200$ cm. and $d = .2$ cm. and $d = 5$ cm.

$$\lambda = 15\;\sqrt{l\,d}$$

In all cases l is supposed to be relatively large in respect to d.

No. 2—Rods with two equal square plates.

Let $l =$ the distance between the plates including the spark-gap; $d =$ the diameter of the rods $a =$ the side of one plate, then

$$L = 2\,l\left(\log_e \frac{4\,l}{d} - .75\right) + 2\,a\left(\log_e \frac{(l + a)^2}{(d/2)^2} + .5\right)$$

$$C = \frac{\frac{\pi\,d\,l}{2}}{2\,\pi\,l\,v^2} + \frac{a_2}{2\,\pi\,v^2\,(l + a)}$$

Multiplying and reducing, approximately

$$\lambda = 2\,\pi\sqrt{2.5\;d\,(l + a) + \frac{a^2\;(a + l)}{2\,\pi\,(a + l)}}$$

No. 3—Simple sphere diametrical spark-gap.

Let $D =$ the diameter of the sphere, $l =$ the sum of the length of both conductors, on each side of the sphere which form the spark-gap; and d the diameter of these conductors; then

$$L = 2\,l\;\left(\log_e \frac{4\,l}{d} - .75\right)$$

$$C = \frac{D}{2}$$

$$\lambda = 2\,\pi\sqrt{D\,l\left(\log_e \frac{4\,l}{d} - .75\right)}$$

If l and d are very small in proportion to D, then this reduces approximately to

$$\lambda = 1.3\ D.$$

No. 4—A plane ring.

Let R = the radius of the ring and d = the diameter of the rod of which it is made; then

$$L = 4\ \pi\ R \left(\log_e \frac{8\ R}{d} - 2.\right)$$

$$C = \frac{\pi\ d}{2}$$

and approximately

$$\lambda\ 4\ \pi^2\ \sqrt{2\ R\ d}$$

No. 5.—Two equal spheres.

Let D = the diameter of the spheres and b = the distance between their centers; then

$$L = 2\ D \left(\frac{1^2}{D^2/4} + .5\right)$$

$$C = \frac{R}{2}$$

and approximately

$$\lambda = 7\ D.$$

The remainder of the shapes of oscillators given are merely modifications of the preceding cases.

The illustration in Fig. 9 shows the most familiar arrangement of oscillator. An ordinary 6″ spark coil is mounted upon a platform upon which are supported two terminals consisting of brass rods on either ends of which brass spheres are placed. The smaller spheres are employed for a spark-gap, while the larger ones are adjusted of such size as to make a capacity approximately of the desired amount. Between the terminal balls a larger sphere, usually about 8″ in diameter, is supported on similar insulated standard. All this apparatus is so arranged as to be adjustable, in order that the relation of the spark-gap and central sphere may be varied. A Morse key is arranged to interrupt the primary circuit so that sparks may be given at pleasure, and the terminals of the coil are so planned as to be connected to an elevated mast and to the ground when desired.

As electric oscillations only accompany a disruptive discharge, the more sudden and violent the spark, the greater is the proportion of energy converted into radiation, therefore, the adjustment of the spark-gap is of vital importance in the construction

of an oscillator. All parts of the apparatus should be carefully rounded to prevent any approach to brush discharge, and the surfaces of the gap should have as large a radius as possible. These surfaces must also be maintained in the highest state of polish, particularly if short waves are desired, for even a few minutes' sparking will so roughen the metal as to prevent the emission of the shortest oscillation. To minimize the labor of re-polishing it is convenient to make the terminals of adjustible cups in which polished spheres may be placed, continually revolved, so as to present fresh surfaces for the emission of sparks. The immersion of the terminals in oil has also been tried with good success, as it largely contributes to the efficiency, permanency and suddenness of the spark action. The length of the spark is another important and very essential consideration, but one which requires adjustment for every different arrangement of oscillator and receiver. A gap either too long or too short will fail. Usually from one-half centimetre to three centimetres in length is fairly successful. The observer soon learns to judge from the character of the spark as to the working of the oscillator. A thin faintly luminous violet spark gives poor results and indicates too small capacity in the apparatus. A thick, heavy, perfectly straight white spark is equally bad, denoting an excess of capacity, while the most efficient spark is jagged and arched and plays about the discharge surface. It appears to have a reddish violet center and to be surrounded with several concentric sheaths of flame. With each reversal of the coil current, the spark is suddenly extinguished with a loud snapping sound, and is also very sensitive to a magnet.

I will now put upon the screen some representations of the coherer. Fig. 10 is a general view of the coherer, while Fig. 11. is a magnification of the coherer which I passed around a few minutes ago. You will see the brass plugs at either end coated with platinum, and the metallic filings in the center.

In the next slide I have an arrangement which I think will illustrate the way in which the coherer works, and it may be interesting to know that it is taken under the microscope from the filings themselves.

Under ordinary circumstances the coherer filings are in the position that you now see, electrically opaque. An electric wave arrives and jostles the atoms into contact, and the coherer becomes electrically transparent. A slight tap destroys the atomic bridges, and again becomes electrically dark, as soon as the next electrical wave appears, it becomes electrically transparent again, and so on; so that the action of the coherer, under a succession of waves, may be illustrated by the operation of this slide on the screen.

I have endeavored, thus roughly, to describe the way in which we make electric splashes in the ether, and the means for diluting the waves. Imagine a blind man standing on the margin of

a pond; he might hear the splash of a stone that was thrown into the water, but he would have no means of knowing anything about the waves which ripple over the surface. Suppose a piece of board placed on the surface of the water, and the blind man to put his hand thereon, the oscillations of the chip, under the influence of the waves, would convey the idea that "Somebody has thrown in a stone."

Without the coherer we have no senses which can detect the electrical waves. We cannot see them, hear them, feel them, taste them; they flow by us, and have for ages, but the coherer is the board that enables us, by mechanical means, to detect their presence. If we can appreciate the presence of these waves, then we can use them for the transmission of intelligence.

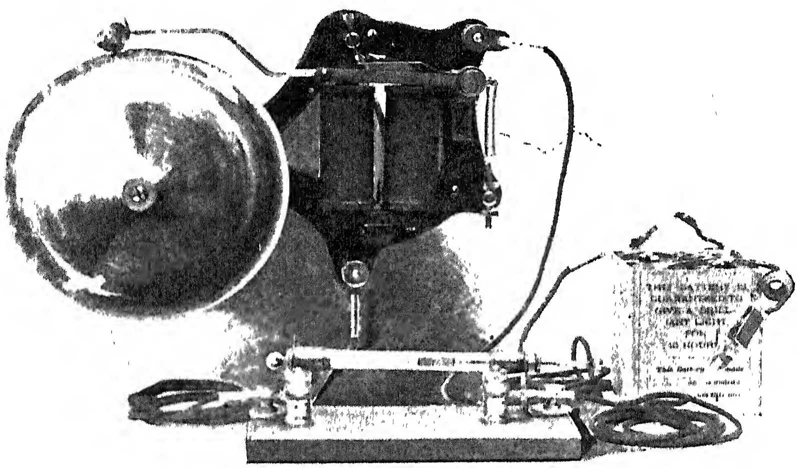


FIG. 14.—Simple Detector for Electric Wave.

In Fig. 14, the simplest form of Hertzian wave detector is shown. The apparatus consists of an ordinary vibrating bell connected to a bicycle battery and coherer mounted upon a brass stand. The coherer, vibrating bell and battery are all in series. So long as no electrical wave impinges upon the coherer its resistance is so high that the battery circuit remains open so far as the bell is concerned, and the apparatus is silent. Upon the impact of an electrical wave upon the filings, the resistance is so lowered that a current is established and the vibrating bell rings. A tap or two upon the glass tube of the coherer with a lead pencil is sufficient to restore the filings to their original condition and interrupt the operation of bell.

We are all familiar with the Morse alphabet. If we can send waves for the tenth of a second and stop, and then send waves for three-tenths of a second, we have what is equivalent to a dot

and a dash, and symbols A. If we send waves for three-tenths of a second and then stop, and then for one-tenth, and stop, and then for one-tenth, and stop, we have D. If we devise means whereby the coherer shall interrupt the battery current as soon as the waves stop, it is evident that we can measure the length of time that the waves are passing through the ether. To do this manually by tapping, is far too clumsy, and some automatic means must be employed. One method is to place in the coherer circuit an electro-magnet. As soon as the battery current is established the electro-magnet is excited, and—if we use the buzzer form arranging the hammer so it shall strike the glass tube, it will tap the coherer and decohere it. That is exactly what happens in this instrument on the table. Here is a coherer similar to that which you

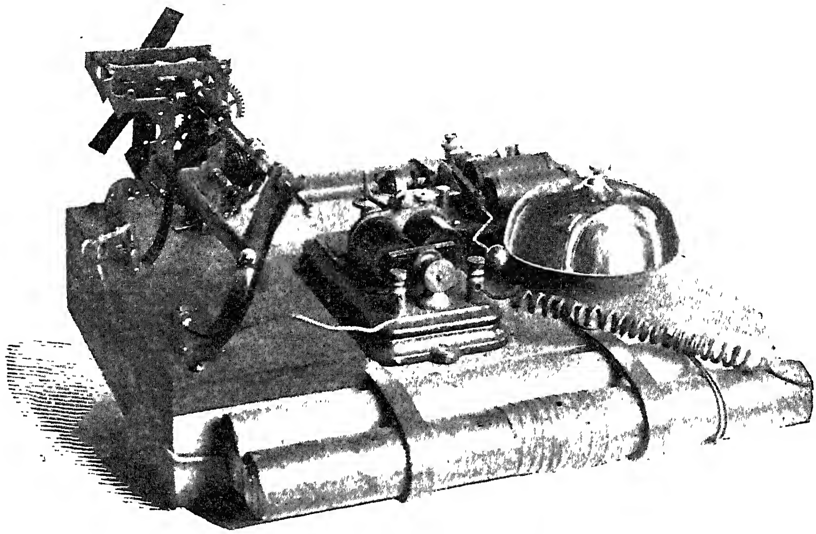


FIG. 15.—Revolving Decoherer.

have seen with the tube supported by springs at each side. Directly underneath is the buzzer, an ordinary electric bell. The electric waves emitted by the coil will excite the coherer; operating the buzzer and decohering the instrument. Let us try the coil. [Circuit made, bell rings but does not stop.] The coherer is adjusted a little too sensitively. I will try and modify it. [Breaks tube.] I am afraid this instrument will not operate any more to-night, because I have broken the tube, and I shall have to have recourse to what my professor of natural philosophy used to tell his students when his experiments did not succeed. "The principle, gentlemen, remains the same, although the experiment failed." In this case, however, the experiment did not quite fail. It worked at least half way until I endeavored to adjust the tube, and broke the coherer. So that I am sorry that

I cannot give you an illustration of the actual sending of a message across the room, as I had expected to do this evening. [See Fig. 18.]

In Fig. 15, another form of decohering apparatus is shown. Upon a small wooden platform a vibrating bell is mounted in the locality of a sensitive relay. The coherer is supported upon the axis of one of the wheels of an ordinary clock, so that when the clockwork is wound up and set in motion the coherer revolves, thus constantly turning the filings over and over in the glass tube. When the coherer is still, and in the absence of an electrical wave, the circuit is open as already described. Touching the key of the oscillator, causes it to emit electrical waves, closing the circuit of the coherer and ringing the bell. If the detent is removed from the clockwork, the coherer revolves, and as the filings tumble over each other its original resistance is im-

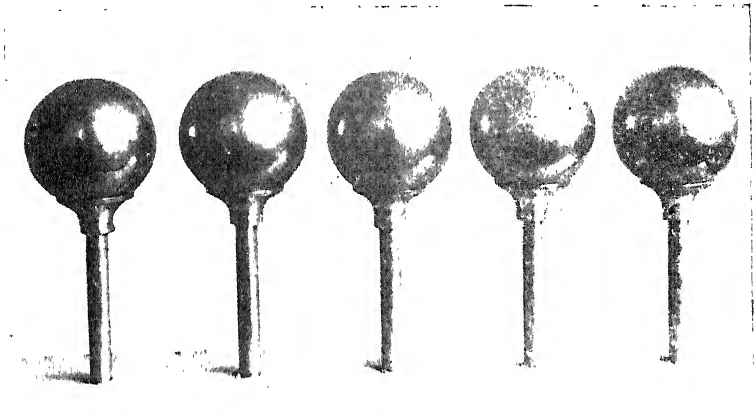


FIG. 16.—Multiple Spark-Gap Oscillator.

mediately restored, therefore this apparatus is always automatically in receiving condition. The objection to it however is that this method of decohering impairs markedly the delicacy of the instrument, as in order to present the maximum sensitiveness the filings in the coherer should always be at rest and ready to receive an electrical impulse.

However, the other apparatus which I have is entirely typical. At the transmitter, there is the induction coil, and a wire rod extending into the air terminating in a brass ball, while the other pole of the coil is grounded. At the receiving station, the coherer is in series with a sensitive relay, the local of which carries a buzzer or hammer, mechanical hammer and a sounder. This is supplied with a similar elevated mast and sphere, while the other terminal is grounded. Exciting the transmitter sends a spherical undulation through the ether,

which, falling upon the coherer, causes the filings to cohere, completing the circuit that energizes the relay, and operates the sounder, sets the buzzer running, and mechanically decoheres the filings, leaving them ready to receive the next wave.

I will now place upon the screen the circuits which I use, and then touch for a moment on the limitations of the apparatus. [Slides are shown]. As bearing upon the commercial value of this method, an inquiry into the efficiency and delicacy of the coherer is interesting. The common six-inch coil takes a current of ten or twelve amperes at a pressure of ten volts, thus absorbing about 120 watts. The efficiency of the coil is not over 30 to 50 per cent.; using the latter amount as most favorable to the coherer, about 50 or 60 watts would re-appear in the spark-gap, the heat, light and sound of which absorb at least 90 per cent. of the energy there expended, thus leaving not over ten per cent. or say five or six watts as transformed into pulsations through the ether. Suppose the coherer to be located at a distance of 50 feet from the coil. The area of the spherical wave is then $100^2 \times 3.14 = 31{,}450$ sq. ft, or 4,500,000 sq. inches. A coherer without wings, exposes a surface of less than a square inch to the electrical oscillations, hence the apparatus can only absorb an amount of energy of about one seven hundred thousandth of a watt, and calculating back to the energy delivered to the coil, the efficiency of about one eight hundred thousandth of one per cent is found. By the use of a receiving mast and the most delicate apparatus, signals have been sent commercially in England over a distance of 80 miles. Merely for the purpose of illustration, suppose the distance to be 35 miles, the coil to consume 1,000 watts and deliver 100 watts as radiated energy, and assume that the receiving station is supplied with a plate of 100 sq. ft. Probably all these quantities are in excess of those actually employed, so that the calculated results will be favorable to the coherer rather than against it. Under such circumstances, the spherical wave will be

$$70^2 \times 3.14 \times 5.280^2 = 420{,}000{,}000{,}000 \text{ (approximately).}$$

and the energy delivered per square foot of surface will be

$$\frac{100}{420{,}000{,}000{,}000}$$

The amount received by the coherer will be

$$\frac{100 \times 100}{490{,}000{,}000{,}000} = \frac{1}{42{,}000{,}000}$$

say one fifty-millionth of a watt, and the efficiency one five hundred millionth of a per cent. While such low efficiency is abhorrent to the commercial instinct of the calculating engineer,

one stands amazed at the delicacy of the apparatus that will so swiftly and unerringly detect such minute quantities of energy as are represented by the amounts of the order of a millionth of a watt.

We see, therefore, that while the instrument is marvellously sensitive, its efficiency is equally marvellously low.

As an illustration, if a man was at the top of this building and wanted to talk to a man in the street, he could put his head out of the window and shout. He would undoubtedly get his correspondent, and equally attract the attention of everybody in the neighborhood. If only one message is to be sent, it probably would pay to shout; but if one wants to talk from roof to basement frequently a speaking tube is supplied. Why? When the unaided voice is used, the vocal organs send out spherical sound

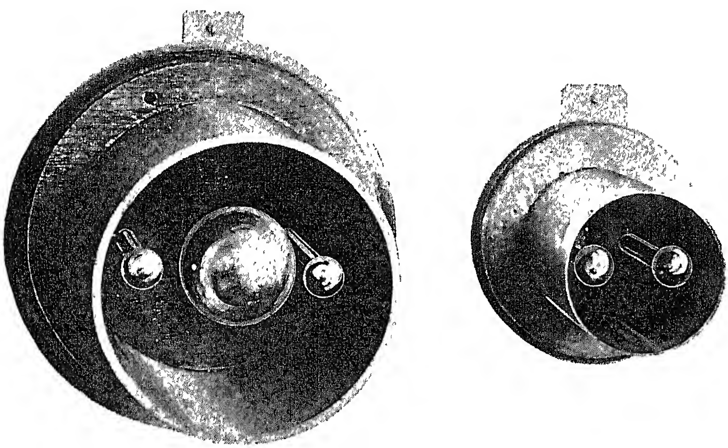


FIG. 17.—Lodge Oscillator.

waves that spread in every direction; but with the speaking tube the sound waves are confined and made to travel along a predetermined route, and the correspondent will receive the whole of the energy except that which is dissipated in heat in the tube.

If there is one message to be sent between the points, it may be a very good plan to use an oscillator and coherer; but if one wants to send a million messages, it is better not to waste so much energy; better build a road for the energy to travel on; and so far the best electrical road is a wire, or to use Lord Kelvin's apt phrase, the hole in the dielectric through which electricity runs. It is much cheaper to build a *hole* than to try to fill the whole of space. So where a number of messages are to be transmited, the cheaper plan is to build a line. Such questions are always finally reduced to considerations of ex-

pense, and the engineer must always, in deciding, calculate what the expense will be, by both methods, and select the cheaper.

If messages are to be sent between two lighthouses, or between a lighthouse and the shore on a rocky coast, where a cable is expensive and must be frequently removed, wireless telegraphy may be cheaper than a cable. If one is to signal between ships at sea, where a cable is impossible, wireless communication solves the problem. Between two moving army corps, where a line cannot be maintained, wireless telegraphy is excellent; but for the transmission of newspaper matter between New York and Chicago every day in the year, it is commercially absurd.

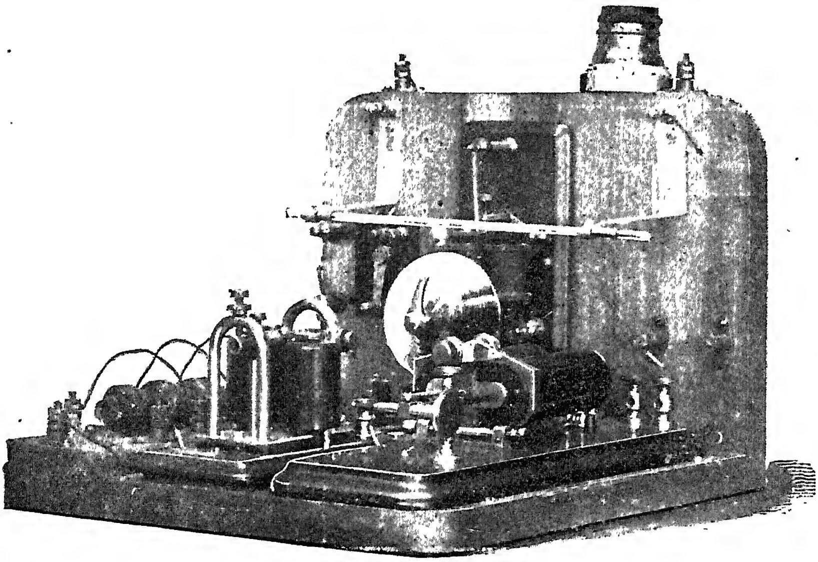


FIG. 18.—Receiver with Electro-Magnetic Decoherer.

Then there are other limitations. It is remarked that wireless telegraphy could not be secret; anyone with a coherer can read the ether waves. Yes; so anybody can read inductively any known form of telegraphy. There isn't a secret telegraph line in the world. Inductively I can tap any telegraph or telephone line, and be undetected. But one can always use a code, and then the man who taps lines, is no wiser than before, unless he is the equal of the cryptogram decipherer in the "Gold Bug." So by this expedient wireless telegraphy, or any other kind of telegraphy, may be just as secret as you wish.

There is another and more formidable obstacle. Assume the coherer and oscillator nicely adjusted, both stations working harmoniously, and you wish to send messages between war ships or moving army corps, or something of that kind, and suppose

that the enemy on another war ship, or the commander of the opposing army corps has an idea that you are about to communicate in that manner; he simply sets up another oscillator and rattles away at his key in any incoherent fashion, your coherer will respond to all waves, and the jumble that results would take a more fertile imagination than that of Edgar Allen Poe to decipher. So wireless telegraphy at the present is an egotistical performance; only one man can have the field at one time· It is stated that it is possible to so synchronize one instrument with another that those two will mutually respond, and be oblivious to all others. This is partially true. A certain amount of synchronism can be established, and instruments made not to respond markedly to those that are much out of tune, but this possibility has not been developed to even an experimental success over greater distances than a few hundred feet as yet.

So, as far as I have studied the subject, the matter may be thus briefly summed up: As a scientific invention, as an instrument of marvelous delicacy, the coherer will go down to the ages as one of the most wonderful instruments man has ever invented. For certain specific cases, under special circumstances, signaling with its aid is of immense value; but at present, and unless there is some improvement, some modification that does not as yet appear, its use will be confined to such special cases.

Mr. Geo. M. Mayer:—I would like to ask Mr. Abbott if there has been any attempt to use reflectors or similar means.

Mr. Abbott:—Yes Prof. Hertz showed that it is possible to reflect electric waves, and Mr. Marconi has made experimental attempts to use them. Electric waves are susceptible of reflection, refraction and polarization, but the practical difficulty is in the construction of the apparatus. Waves, such as we are using, vibrate about 200-millions per second, and the wave-length varies from a few inches to several hundred feet. Now imagine the difficulty of building a reflector large enough to embrace such waves: or the possibility of grinding its surface so accurately that the wave would not be distorted perceptibly in projecting it 100 miles, what would the reflector cost? The Yerkes lens cost something like $50,000, and it is forty inches in diameter. What would the probable expense of a lens for electric wave be? Probably not proportionately as great, but for transmission over the same distance, for commercial work, a wire is cheaper.

Mr. Thomas Duncan:—I would like to ask Mr. Abbott, whether anybody has succeeded in getting the wave-length down to two and a half inches.

Mr. Abbott:—The shortest wave-lengths that have been recorded, are by Dr. Lodge, and are three to four inches long. You remember I showed you that the length of the wave was equal to three tenths times the diameter of the sphere used on the oscillator. By using a sphere small enough, we can reduce the wave-length. The electric waves that we are using now, have a

rate of about 200-millions per second. Light varies from 450 to 730 trillions per second. Mathematically, if a sphere was used small enough, one could get electric waves as short and quick as light waves. Then we would have light without heat, but the dimensions of a sphere sufficiently small are about what we suppose to be the dimensions of the atoms; and therefore from our present knowledge, light is an oscillatory vibration of atomic electric charges, and if at any time we can succeed in devising any means for vibrating the electric charges of atoms, we shall have cold light, and we shall not have to spend ninety-five per cent. of our coal energy in getting five per cent. of light out of incandescent lamps.

MR. JAMES LYMAN:—I would like to ask if the coherers cannot be made of different sensibilities, so that it would be possible to have a set of coherers operating on our vessels that will not be sensitive to the users of other oscillators that might be set up with the object of preventing signaling, or with the object of setting up other signals.

MR. ABBOTT:—Yes, and no, in this sense; that the sensitiveness of the coherer is a function of three things; it varies as the capacity, the pressure upon the filings, and the chemical condidition of the metal. It is conceivable that you can make a coherer which will be sensitive to one set of waves and insensitive to another set, because a different amount of energy is delivered to the different coherer.

As far as the construction of the coherer is concerned, it may be interesting to note that the sizing of the particles must be carefully done. They must be very sharp and of non oxidizable metal. Gold, silver and platinum make much more sensitive coherers than the oxidizable metals.

MR. V. R. LANSINGH:—What is the present limit of satisfactory working of the system?

MR. ABBOTT:—They claim in England a distance of 90 miles. The longest actual distance that I have known of its being successfully worked is something under 70 miles.

MR. LANSINGH:—How rapidly can the key be worked?

MR. ABBOTT:—You can readily see that this sort of apparatus must be worked very slowly. The best speed that has been attained is about eighteen words a minute. The average transmission is about six to eight words per minute.

[Adjourned.]

[COMMUNICATED AFTER ADJOURNMENT BY W. S. FRANKLIN.]

I have been much interested in the discussion of wireless telegraphy published in the December number of the TRANSACTIONS. Dr. Pupin, as it seems to me has made several erroneous statements in calling attention to the great importance of a small logarithmic decrement in the transmitting and receiving circuits. In the first place he would have it appear that the logarithmic decrement depends mainly upon the resistance of the respective circuits, while it is well established theoretically that the dissipation of energy by radiation is much more prominent in determining the decrement of electrical oscillations except in those types of oscillators which do not radiate to any great extent, which types are not suitable for transmitting circuits. In the second place the use of successive impulses in the sending circuit for increasing the oscillation in the receiving circuit does, as it seems to me, require each successive impulse to be in proper *step* with the foregoing impulse as pointed out by Mr. Mailloux. To realize this condition in practice would be next to impossible, and it seems to me that we must be content with the oscillations produced in the receiving circuit by one impulse in the sending circuit with its trail of decaying oscillations.

In the third place, the electrical oscillations of a conducting staff perpendicular to an infinite conducting plane, are precisely the same as the oscillations of an isolated staff of double length. Dr. Pupin would have it appear that the staff and plane is a distinct and much more complicated oscillating system.

In the fourth place it does not seem that small logarithmic decrement is of any importance in determining the range of signaling, for the decrement is due mainly to radiation of energy and the intensity of the oscillations produced in the receiving circuit by a few intense waves is about the same as would be produced by a greater number of less intense waves representing the same total amount of energy, although the receiving circuit would need to be more accurately tuned in the latter case to give the full effect and therefore, the latter case makes it more feasible to realize selective signaling. Also slow oscillations (and long wave-length) allow the receiving wire to gather into itself a wider band of the passing waves, so that a greater effect would be produced by a given amount of energy expended in the sending circuit.

THE PRESIDENT:—Is there any further discussion of this paper? If not, we will proceed to the second subject for the evening which is a paper on "An American Pacific Cable" by Capt. George Owen Squier.

A paper presented at the 138th Meeting of the American Institute of Electrical Engineers, New York, December 27th. 1899. President Kennelly in the Chair.

AN AMERICAN PACIFIC CABLE.

BY GEORGE OWEN SQUIER.

It is interesting to note that the idea of a trans-Pacific submarine cable was first discussed and considered by the late Cyrus W. Field, nearly thirty years ago The scheme of Mr. Field and his associates involved a route from California via Alaska and the Aleutian Islands to Japan. Since that date, the subject in some form has been almost constantly before this country and Great Britain. This question has been discussed in the fifty-second, fifty-fourth and fifty-fifth Congresses, in each of which effort was made looking towards laying a cable at least as far as the Hawaiian Islands.

In a special message to Congress, dated February 10, 1899, the President says:

"As a consequence of the ratification of the treaty of peace between the United States and Spain, and its expected ratification by the Spanish Government, the United States will come into possession of the Philippine Islands, on the farther shore of the Pacific. The Hawaiian Islands and Guam becoming United States territory, and forming convenient stopping places on the way across the sea, the necessity for speedy cable communication between the United States and all these Pacific islands has become imperative. Such communication should be established in such a way as to be wholly under the control of the United States, whether in time of peace or of war. At present the Philippines can be reached only by cables which pass through many foreign countries, and the Hawaiian Islands and Guam can only be communicated with by steamers, involving delays in each instance of at least a week. The present condition should not be allowed to continue for a moment longer than is absolutely necessary."

The idea of a British Pacific cable, connecting the Dominion of Canada with the Australasian colonies, almost from the first has been discussed from a national standpoint. Her Majesty's Government and the colonial governments most concerned, have been urged from time to time to consider the matter in its strategic and commercial aspects. Two colonial conferences, in 1887 and 1894, were largely occupied with this subject, as evidenced by the exhaustive blue books which record their proceedings. The Dominion Government took the matter up in 1893–4, and invited the most reputable firms in the world to submit estimates for construction and laying.

In 1896, Mr. Chamberlain, Secretary of State for the Colonies, appointed a Pacific Cable Commission, which included among its members the Under Secretary of State for the Colonies, the High Commissioner of Canada and the Agents-General for New South Wales and Victoria. This committee went into the whole subject of the practicability, cost, probable revenue, and management of the proposed enterprise and elicited a fund of technical, commercial, and professional information upon cable manufacture and cable laying in general, and upon this important project in particular, which is invaluable, and which probably could not have been obtained in any other manner. At this moment a Pacific cable touching only soil belonging to Great Britain is assured, both Canada and Australasia recently having been reported as joining with England in pledging themselves to the enterprise as a government undertaking.

The proposed route with surface distances involved, is shown on the accompanying map, and is from Vancouver to Fanning Island, thence to the Fiji Islands, thence to Norfolk Island, and from there bifurcating to New Zealand and Queensland.

Since a Pacific cable will at last complete the telegraphic circuit of the globe, it will give the peculiar advantage of placing each point thereon in cable connection with every other point by *two* distinct routes either east or west.

The cardinal idea in the British system has been that all state cables shall touch only British soil, and this principle has placed British cable traffic in the Pacific forever at a disadvantage over the American cable for the reason that the only available route involves a single span of cable from Vancouver to Fanning Island, over 3,500 miles in length; whereas, by the annexation of the Hawaiian Islands, the United States, while following a

similar principle, will have no span longer than the present Atlantic cables, or about 2,500 miles in length.

Since the speed of cabling decreases in general with the square of the length of the cable, and the speed of the whole system is limited by the speed of the slowest span, that system requiring the longest single span is ultimately at a disadvantage, provided the systems are in direct competition. In the projected Pacific cable enterprises, however, although, as will be pointed out later, they will operate in close relations with each other, yet each has a sufficient prospective traffic to guarantee the enterprise as a sound financial success from the beginning.

American Cable Routes.

In the consideration which, from time to time, has been given the project of spanning the Pacific ocean by a submarine cable, the Northern route, via Alaska, the Aleutian Islands, Siberia, and Japan has been frequently proposed.

In recent years the British Government, in its proposed line from Canada to Australasia, first projected this northern route owing to the absence, at that time, of information respecting the southern Pacific ocean, and the impression which prevailed that physical difficulties existed which offered insuperable obstacles to the laying of a cable on a direct route between Canada and Australasia. In consequence of this impression it was designed to lay the cable from Vancouver to Japan, touching at islands in the Aleutian and Kurile groups as mid-ocean stations. From Japan the connection with Australasia would have been obtained via Singapore and the Eastern Extension Company's lines of telegraph. Through the intervention of the government, negotiations were opened with the view of securing one of the Kurile Islands. Japan was asked to transfer to the British crown one of these islands in order that the telegraph station should be under British protection, and an agent was sent to Washington who, after some difficulty, obtained conditional landing privileges on one of the Aleutian islands

Recently there has been a revival of interest in this route, especially now that the growing commercial interests of Alaska are becoming important. The plan proposes starting from Cape Flattery, thence to Sitka, distances (approximate) 803 miles; thence to Kadiak Island, 682 miles; thence to Dutch Harbor,

770 miles; thence to Attu, 810 miles; thence to the Japan-Russian border, 858 miles, thence to the Japanese land lines, 810 miles; from the Siberian border to the Siberian lines, 617 miles; and from Formosa to Luzon, 200 miles; in all 5550 nautical miles, exclusive of the Japanese system.

It will be noticed that this series of cables aggregating 5550 miles makes no provision for American communication with the Philippines, except over the Japanese land lines from the north point of Japan to the south point of Formosa, a distance through a foreign territory of about 1200 miles. Owing to the uncertainty of the Japanese land lines, which are frequently interrupted during the typhoon season, particularly in Formosa, it would be necessary, in order to ensure communication, to extend the Japanese cable system. Again, the Great Northern Telegraph Company, a Danish corporation, has exclusive rights, not only on the Siberian coast but also between Japan and the Asiatic coast.

Apart from establishing telegraphic communication *free from foreign control* between the United States, the Hawaiian Islands, the Philippine Islands and the island of Guam, the mission of an American Pacific cable should be to bring about a general reduction of cable rates.

On the Alaskan route, a large number of intermediate stations must be established and maintained; and there must be a division of receipts with Japan. A message via Honolulu, an intermediate island station and Guam, would reach Luzon by four cable transmissions. The Alaskan route as proposed would necessitate about fifteen separate stations, of which nearly one-half would be under Japanese control.

Undoubtedly an Alaskan cable will soon be required, and apparently also the extension of such a cable system as a means of attaining a through line to the Philippine Islands is an attractive plan. This plan, however, leaves the United States in practically the same unsatisfactory position she is in at present in respect to communication with her Pacific possessions, and until definite and perpetual concessions are forthcoming, can furnish even no guaranty of substantial reduction from the present high rates.

It is believed that no one studying the true present and future interests of the United states can come to any other conclusion relative to an American Pacific cable, than the one so admirably

expressed by the President in his special message to Congress, *viz.* that this cable shall be "wholly under control of the United States."

This cardinal idea—the principle also adopted by Great Britain, after years of exhaustive consideration—at once excludes the northern route for the present, and limits the route to American territory.

PRACTICABILITY.

There is no longer any doubt as to the practicability of the Pacific cable project from a technical and engineering point of view. A preliminary survey between the coast of California and the Hawaiian Islands was completed by the Navy department in 1892,[1] showing the entire practicability of this part of the route. Between California and the Hawaiian Islands several approximately parallel routes are practicable, but the one which seems to be favored by the survey of 1892, as shown in the report of the Hydrographic office of the Bureau of Navigation, is a rhumb-line between Monterey Bay and Honolulu on Oahu Island. The U. S. S. *Nero*, under command of Commander Charles Belknap, U. S. N., has been engaged since April last in a survey of the bed of the Pacific along the proposed route of the cable from the Hawaiian Islands westward to the Philippine Islands and to Japan. A preliminary report of this survey recently received, adds greatly to the knowledge of this part of the Pacific and to the data necessary before determining the exact route of the cable. This survey develops two unusual physical features along the route via Midway Island, one of these is a submarine mountain, situated a short distance westward of the Midway Islands and rising from the floor of the ocean, having a depth of 2,200 fathoms to within 82 fathoms of the surface. The second feature is one of the deepest submarine abysses yet found in the world, situated about 500 miles eastward of Guam and more than 4900 fathoms in depth. These and other obstacles which may be found, however, can be avoided in laying the cable by making suitable detours around them as is ordinarily done.

A MID-OCEAN ISLAND CABLE STATION.

The great decrease in speed and increase of cost consequent upon increase of length of a single span of the cable, necessitates a landing station, if possible, between the Hawaiian Islands and

1. See Senate Document 153.

Guam. The longest cable yet laid and in operation is the French cable from Brest, France, to Cape Cod, Mass., which is about 3,250 nautical miles in length, and there is no question that a cable directly connecting Honolulu and Guam could be successfully laid, if no practicable landing place between these points could be obtained. This single span, however, about 3,650 nautical miles including "slack," would for all time so reduce the through speed of the cable, and so increase the original cost, as to warrant unusual expense, if necessary, in preparing and maintaining an intermediate station. In this connection the large amount of technical evidence given before the British Pacific Cable Committee relative to the Vancouver-Fanning Island span, which is practically the same extreme length of 3,600 nautical miles, and of the utilization of Fanning Island as a station, are valuable as showing entire practicability. Although both Wake and Midway islands, which have been proposed as stations, are low atolls, rising but a few feet above high water and with little to sustain human life, yet either of these places is equal, if not superior, to Fanning Island. Further careful surveys will be necessary before the exact route west from the Hawaiian Islands to Guam can be finally determined. Fortunately for this enterprise, the annexation of the Hawaiian group brought under the sovereignty of the United States eleven or twelve small, rocky or sandy islands extending to the northwestward about 1,800 miles from Honolulu. These must be surveyed and considered from the cable standpoint before a final selection of route can be made.

The distances in nautical miles along two provisional routes, including ten per cent. for "slack" in laying, are as follows:

San Francisco to Honolulu	2,286	miles.
Honolulu to Midway Island	1,254	"
Midway Island to Guam	2,523	"
Guam to Dingala Bay, P. I.	1,496	"
Total via Midway Island	7,559	"
San Francisco to Honolulu	2,286	miles.
Honolulu to Wake Island	2,205	"
Wake Island to Guam	1,435	"
Guam to Dingala Bay, P. I.	1,495	"
Total via Wake Island	7,422	"

In Appendix I. are shown the great circle and rhumb line distances involved, and the geographical positions used.

Cost, Maintenance and Operation.

The cost of laying cable depends mainly upon the materials used in its construction, and therefore fluctuates with prices current. The outer coverings are much the same in all specifications, according to the conditions of the case, but the copper conductor and the gutta-percha insulation vary with the speed required over the cable. Since the length of the longest section of the proposed Pacific cable is approximately equal to each of several of the Atlantic cables, the type of the cable to be used for this section, and the speed obtainable are subject to a close estimation.

Of the eleven cables spanning the north Atlantic, the Anglo-American Company's cable laid in 1894, and the Commercial Cable Company's cable No. 3 laid also in 1894, have the greatest speeds. The former contains 650 lbs. of copper and 400 lbs. of gutta percha, and the latter 500 .lbs copper and 320 lbs. gutta percha per nautical mile. Either of these types of cable would give good results and no cables of less equivalent speed should be considered.

The following conservative estimate is made from the evidence obtainable relative to the establishment of this enterprise by the government on a sound financial basis:

Maintenance and Repair Per Annum.

Annual expenses of two cable repair ships	$200,000.
Annual expense for new cable, assuming entire cable to be replaced in 40 years, or 200 miles per year,	200,000.
Working expenses,	125,000.
Reserve fund, and interest on capital,	400,000.
Total net earnings of cable required,	$925,000.

This provision for laying 200 miles of new cable per year should perpetually maintain the value of the cable as an asset, and the reserve fund further provides that the entire capital shall be replaced at the end of fifty years, or what is equivalent, that a sinking fund shall be established, which, at the end of fifty years will be sufficient to lay an entire new cable in addition to the permanent maintenance of the original one, so that at the end of fifty years, two working cables will be provided for.

Taking average conditions for long cables ten years ago, the annual expenses for maintenance and repair, *e. g.*, for new cable required, etc., and not including the fixed expenses such as the repair ships, was about $30 per nautical mile. The great

advancement in cable manufacture since has reduced the average repair rate materially, but assuming this rate as it then averaged, the total charge to this item is practically the same as that given by the independent supposition above.

At present there is no first-class cable ship in the world flying the American flag and which would therefore be under the control of the United States in time of war. It should be the policy of the United States, whether the Pacific cable is laid by the government or by a subsidized company, to require that two complete cable repair ships, one, at least, also capable of laying long cables, equal to any yet constructed for these purposes, and flying the American flag, be stationed in the Pacific ocean.

Speed.

The "speed" of a cable is a somewhat loose expression and depends upon the voltage used, the particular apparatus employed in working the cable, as well as the design and construction of the cable itself, and the skill of the operators. Besides, there is a considerable margin between a speed which will do for press matter in ordinary plain language, and the speed permitted for code and cipher messages.

"Speed" expressed in words per minute is misleading, since five letter words are frequently taken as the basis, whereas in actual practice a telegraphic word averages about eight letters, the increase being due to code words, and the omission of many conjunctions and prepositions when messages are sent in clear. A better method of expressing speed in cabling is in standard letters of a certain number of signals each, transmitted per minute, so that experienced operators can certainly and easily read them. The practical speed is the proportion of the maximum speed which remains after deductions are made for the words transmitted for which no revenue is received, on account of service prefixes, etc., repetitions, errors, corrections. necessary interval between messages, administrative messages connected with traffic, etc. In determining the deductions from the maximum speed to obtain the practical speed in paying words per minute there is little evidence at hand. In the perfected management of the Atlantic cables where keen competion exists, this "dead" traffic has been reduced to sixteen or seventeen per cent. of the whole. For a Pacific cable an amount of "dead" traffic as great as 30% at first is estimated, and this could probably

be reduced in successive years as it has been in the Atlantic traffic. Assuming 30% for "dead" traffic, and an increase of 90% of speed for duplex working it is estimated that the maximum capacity of the cable in total paying code words, of eight letters each, would be about 11,800,000 per annum. The cost of maintenance and operation, etc., as above being $925,000 per annum, the average cost of transmission per telegraphic word is about .08 cents.

In connection with speed of cabling it may be said that the opinions of the best cable experts in the world as to the theoretical speed obtainable from a given cable over a given distance differs so widely as to inspire caution in making all estimates.

The present commercial rate from Washington to Manila is $2.38 per word, Government rate $2.255 per word, and the rate for "right-of-way" messages three times the normal rate.

It is seen that at the present commercial rate to Manila, after allowing for present land rates to San Francisco, the proposed cable is required to operate less than fifty minutes per day in order to earn the income of $925,000.00 per year. Allowing the present rate to be reduced one-half, the cable would have to work less than two hours daily. If the rate per code word, of an average of eight letters, is placed at fifty cents from San Francisco to Manila, then, upon the above supposition, the cable need operate daily less than four hours to meet expenses.

Assuming the cable to be interrupted as much as one-quarter of the entire time, the figures above still appear striking.

The desirability of the cable from an economic standpoint seems unquestioned. The Secretary of War says in his annual report:

"The cable tolls of the War Department messages alone to and from the Philippines for the last five months have averaged monthly a rate of over $325,000.00 a year."

This alone equals the interest at three per cent on the sum of $10,845,000. It is reasonable to assume that the despatches of the other departments of the Government would at least increase this amount by one-quarter, which would make the present Government cable tolls to and from the Philippines equal to the interest at three per cent. on approximately $13,500,000. Fully 90% of this sum goes to foreign corporations while all Pacific cable expenditures would remain in the United States.

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telegraph and cable letter service at rates comparable with present postage rates will be realized throughout the world, with its consequent revolutions in business and social methods. Time has an international money value. The fastest mail express, or the swiftest ocean mail ship, are as naught compared with the velocity of the electrical impulse which practically annihilates any terrestrial dimension. As the distance increases, electricity surpasses steam in a continuously increasing ratio. In the case of a message to be sent across the street, probably there is no more efficient and satisfactory method than by a mail delivery messenger, but if this message is to be sent half way around the earth, the minutes required by the telegraph run into weeks and months by the slow process of the mails. Steam time is directly a function of the distance to be traversed, and from the nature of things must require twice as long to go two miles as one. If then the cable saves six days between Europe and America, it will save more than twice this time between America and the East, and is from this point of view correspondingly important and necessary. Since electricity so far outstrips any other known vehicle for transmitting intelligence it must eventually carry all the important information and practically take from the present mails more and more of the most urgent letters.

Continuous Use of the Cable Proposed.

With a Pacific cable in operation, and possessing such immeasurable advantages over the mail, how can any management be entertained which does not aim at the use of the cable continuously to its fullest capacity? Cable property is peculiar in that it does not, like mechanical machinery possessing moving parts deteriorate with use, and its life is not therefore dependent upon the amount of traffic transmitted. The ordinary manufacturing plant is usually not operated continuously because the coal consumption, the wear and tear of machinery, and the extra expense of employees—combined with the state of orders received, do not present a sufficiently attractive economical proposition. But a large cable property presents unique conditions from a purely business standpoint. The bulk of the capital invested is buried under the sea, and much the largest item to be earned is the interest on the capital. A 2000-mile line requires but two operating stations, and the annual expense of a few clerks who actually operate the plant, forms a comparatively insignificant part of the total annual expense.

In the estimate of Mr. Alexander Siemens upon the British Pacific cable in a paper at Ottawa in 1894, but 12% of the total annual expense was for operating staff proper, and this also provided for more than double the usual wages, in consideration of the isolated positions of the mid-ocean stations. Add to this the fact that what ordinarily corresponds to coal consumption, here consists of a few electric batteries, and is therefore practically nil, and also the fact that using the plant causes no deterioration, and the logical business conclusion is reached that ocean cables should be kept busy continuously. Every hour they remain idle is so much service absolutely lost. Present cable tariffs are so high as to force to idleness for a considerable portion of each twenty-four hours all of the long cables of the world. In addition the Atlantic cables are practically silent one day in seven.

In defense of the present management, too often unjustly criticized, it is submitted that cable property on the whole has been particularly hazardous and uncertain; repairs often most expensive, and a prudent management has required large sinking funds and reserves. Furthermore, the necessary traffic arrangements required with co-operating or competing companies establish precedents and form obligations not easy to suddenly change. The whole of cable history does not yet cover fifty years, but the skill and experience of the large cable manufacturers in England have brought this industry to such a state of perfection that the laying of a 2000-mile ocean cable, or its repair, in 3000 fathoms, is no longer considered a particularly hazardous undertaking. In fact, in the beginning, cable rates had to be high, and although there has been a steady decrease in rates to the present, as the technical side of the business has become more stable and certain, yet it is believed that the time has now arrived when a more extensive classification and reduction can be inaugurated with advantage both to patrons and to revenues earned.

As a practical means for operating the cable continuously, it is a natural suggestion to classify the traffic offered and establish differential rates therefor as is now universally done on land lines. The same causes which have established night rates on land are much more potent in case of ocean telegraphy where the time gained and the capital invested per mile is enormously greater. It is simply a matter of paying for time. The stock exchange message where minutes are valuable should be charged

the highest rate, while the press and less urgent business messages should be classified and paid for according to the time limit called for in delivery. Since the only other competitor in the Pacific is the mail steamships where the minimum time is over two weeks, it should be easy both to create new business and to draw from the mails as desired. In handling certain classes of messages it can be distinctly agreed to deliver only within a certain number of hours or a week or even establish a low Sunday rate for certain classes of matter, and still arrive much ahead of letters sent by mail. If we have no less than four classes of matter in the present mail system by steam train, why not a classified service for an ocean cable postal system where the reasons for it are more potent?

For the fiscal year ending June 30, 1898, the amount of mail matter, letters proper, excluding all other forms of mailable material, carried in mail steamers from the United States across the Pacific Ocean for Japan, Hong Kong, Shanghai, Manila, Singapore, Cochin China, Java, and Siam was about 10,948,651 grams, representing about 1,156,176 letters. From the United States for Hawaii, 3,495,442 grams, representing about 369,072 letters. This reveals the appreciable proportion of the Pacific traffic which stops at the Hawaiian Islands, being from the above figures about 25% of the entire traffic which in 1898 left the United States for these countries. These figures are instructive as indicating that in considering the through trans-Pacific cable, the Hawaiian traffic is not entirely to be ignored, and that of the entire length of the cable, the span between California and Hawaii will continuously be required to carry a materially greater portion, and will, therefore be the first span requiring duplication.

Assuming as above that the carrying capacity of the proposed cable be equal to that of the best Atlantic cables for corresponding lengths, it is of interest to obtain in a general way the amount of traffic which can be handled across the Pacific under a management which ensures the cable being used continuously.

The proposed cable should possess a carrying capacity each way per annum of about 5,900,000 code words of eight letters and this allows 30% of the entire amount as waste or non-paying traffic. This means, of the 1,156,176 letters which in 1898 were transmitted to Japan, Hong Kong, Shanghai, Manila, Singapore, Cochin China, Java and Siam, this entire number could have been transmitted by cable, allowing for each communication

about five words of eight letters each. Since the use of code books for cable messages has so much increased that practically all cabling is now transmitted in this manner, we can reasonably take one word equivalent to five by their use, so that each communication above referred to is equivalent to twenty-five words of average length.

Means for Duplication.

All important sub-marine cables should be duplicated as soon as possible. Cables are always liable to interruption from a variety of causes, and the interruption of a single line necessarily suspends all communication. The protection of the patronage requires duplicate lines if for no other reason.

An adequate plan for a Pacific cable should consider means for the duplication of the line. In this connection an examination of the Pacific ocean, and the route of the proposed British Pacific cable from Vancouver to Australia, suggests a span of cable of international value. Reference is made to the desirability of connecting Hawaii and Fanning Island with an Anglo-American cable, operated by the governments concerned, under rules mutually acceptable. A common interest should lead to the linking together of these two great ocean telegraphic routes in the mid-Pacific.

With this single span of cable laid, which is but about 950 nautical miles in length, or but 13% of the length of either of the main lines, it results that each country has practically ensured its line against a total interruption until such other duplicate lines can be laid as the growth of the business will undoubtedly warrant.

Thus in case the British cable between Canada and the mid-Pacific should be interrupted, it would only be necessary to route the British business for Australia, arriving at Vancouver,—over the United States land lines to California to be transmitted over the United States cable to Hawaii, thence over the international span to Fanning Island, and on to Australia via the British line; or in case the American span to Hawaii is interrupted, the United States can likewise reach these islands and the East by routing traffic to Vancouver for transmission to Fanning Island, and thence to our trans-Hawaiian cable also via the international cable span.

In a similar way, in case any section of either through cable is interrupted beyond the Hawaii-Fanning span, the urgent

United States traffic can be routed from Hawaii westward via Australia and thence to the East, or the urgent British business can reach Australia via Manila.

It is believed that such a living and equitable arrangement can be effected in the working of these Pacific cable systems as would afford security to each and result in mutual traffic advantages to both enterprises. Thus there is no reason why the present Atlantic cable system and the United States land systems should not eventually serve as material feeders to and from Australasia, and likewise the British and Canadian systems supply an appreciable traffic to the Philippines and the East.

Cable Connection with the Samoan Islands.

The interests of the United States in Samoa will be more clearly defined by the acquisition of sovereignty over the island of Tutuili now reported probable. In this connection another branch of cable is suggested, which the United States could properly assist. As shown upon the accompanying map, a span of cable but 650 miles in length connecting Fiji with Apia, would thus join the Samoan group to the main British Pacific cable route and furnish cable connections for the three governments interested, viz. England, Germany, and the United States..

Conclusion.

After several years of comparatively little advance, the technical and scientific side of telegraphy has received much attention during the past two or three years, until at this moment there is no other special branch of electrical engineering which is more in evidence or promises more for the future.

By whatever method the first Pacific cable is ultimately laid, and provided that it shall appear that all of the projected cable cannot be manufactured and laid in the United States within a reasonable time, it seems plain that the encouragement of American manufacturers in the building up in the United States of a deep sea cable industry of the first-class is a wise policy for this Government.

The successful completion of the submarine cable across the Pacific will mark an epoch in the telegraph history of the world. After thirty years of consideration—technical, commercial and political—the end of this century sees this great enterprise at last seriously undertaken. The full influence which it will exert

upon the Western Hemisphere and the world in general is not easily appreciated. Strategically, the importance of this intercolonial communication and its preservation are very great. However, the Philippine question should not overshadow the larger question—the Eastern question—in the consideration of this project. Important as the cable will be as a means of joining the Philippine archipelago to the United States, its larger importance will ultimately be in the future of the commercial development between the United States and the East. In the broad extension of the Pacific trade consequent upon the completion of the Isthmian canal and the development of steamship lines plying the Pacific, the telegraph cable will naturally become an important factor. The trans-Pacific steamship lines are heavily handicapped by the absence of a direct means of telegraphy between the ports embraced in their routes. Situated on the main trade routes leading from the Isthmian canal to Asiatic ports, the Pacific cable will serve as a powerful adjunct and support to this enterprise. The two go hand-in-hand and are mutually closely related. It can be stated that there is scarcely any point in the world where there is greater need for a central cable station than in the Hawaiian Islands. Geographically situated at the military and commercial strategic position of the North Pacific ocean, it will ultimately serve as the distributing center of ocean communication between the two hemispheres, as well as to various island groups of the Pacific.

As to the probable traffic to be immediately expected there is little direct evidence at hand, since the waters spanned have never before been crossed by a submarine cable. Taking $150.00 as the average earning power per nautical mile of the long cables of the world as a basis, this project should prove a paying investment from the very first, but it is believed that this estimate, based upon the average of cables will prove under rather than above experience, particularly as this route will immediately enter as a competitor for European traffic via the Atlantic cables and United States land lines. The immediate effect of the trans-Pacific cables will be to lower the rates to the East, since European traffic will be open to competition, east and west, and the new Western route, due to the long spans and comparatively few repetitions will have an advantage.

A short span of cable of about 200 miles between Luzon and Formosa connecting with the Great Northern Telegraph Com-

pany's route through Siberia and also between Luzon and a Chinese port will bring Japan and China into direct connection not only with the North American Continent, but also by two competitive routes east and west with Europe. In fact, the laying of the Pacific cable should operate to readjust the present cable through-tariff rates throughout the world upon a lower basis.

Appendix No. 1.

PROJECTED PACIFIC CABLE.
Distances in Nautical Miles.
(United States Coast and Geodetic Survey.)

PROVISIONAL ROUTES.	Great Circle.	Rhumb Line.	Great Circle Distances + 10 per cent. slack.	Great Circle Distances + 15 per cent. slack
San Francisco to Honolulu	2078.43	2086.86	2286.27	2390.19
Honolulu to Midway Island...............	1139.98	1140.95	1253.97	1310.97
Midway Island to Guam	2293.64	2299.25	2523.00	2637.68
Guam to Dingala Bay, P. I......	1359.95	1360.50	1495.94	1563.94
Totals..........	6872.00	6887.56	7559.18	7902.80
San Francisco to Honolulu......	2078.43	2086.86	2286.27	2390.19
Honolulu to Wake Island..........	2004 27	2008.23	2204.69	2304.91
Wake to Guam...........	1304.43	1305.08	1434.87	1500.09
Guam to Dingala Bay, P. I.............. .	1359.95	1360.50	1495.94	1563.94
Totals.................................	6747.08	6760.67	7421.77	7759.14
Guam to Yokohama......................	1348.05	1348.12	1482.85	1550.25

1 mile=1853.25 metres or 6080.2 feet.

Geographical Positions Adopted.

San Francisco, California, Fort Point, Golden Gate.
Honolulu, Hawaiian Islands, Harbor Light.
Midway Island, or Brooks Island, Welles Harbor.
Wake Island, center.
Guam, Fort Sta. Cruz, San Luis de Apra.
Dingala Bay, Luzon Island.
Yokohama, Japan, English Naval Storehouse.

The nearest point of the main land from Honolulu is Point Arena, next Point Reyes, next Point Sur, California. Taking the positions of the lighthouses the distances to Honolulu are as follows:

From Point Arena . ...2045.7 Nautical Miles.
" Point Reyes............... ....2057.5 " "
" Point Sur...... ....2078.4 " "

As evidence of the importance of particular secret manipulation during manufacture, independent of the weights of materials employed, and the measured K. R. of the finished cable, Messrs. Siemens Brothers & Company have lately issued a table of Trans-Atlantic cable speeds from which the following data is taken :

TRANSATLANTIC CABLES.

Tabular Statement of actual and calculated Speeds.

Date when laid.	Designation of Cable.	Length in nautical miles.	Type of core of Deep Sea cable. Lbs. per nautical mile.	K. R. *Ohm* × *Micro-farads.* $\div 10^6$	Speeds actually obtained in regular working. 5 letter words.	Calculated speed if lengths 1,860 naut. miles.	Calculat'd speed if lengths 1,850 naut. miles and core 650/400.
			Cop. G.P.				
1873	Anglo-American.	1876	400/400	3 919	....	....	....
1874	Anglo-American.	1837	400/400	3.512	20.2 (a)	19.9	28.2
1875	Dir't United States.	2423	400/360	7.558	22.6 (b)	38,6	70.2
1879	Pouyer-Quertier.	2242	350/300	6.600	22 (c)	32.2	59.8
1866/80	Anglo-American.	1852	....	4.632	....	....	....
1881	Jay Gould.	2518	350/300	7.834	21.5 (d)	39.8	69.4
1882	Jay Gould.	2563	350/300	8.030	21.5 (d)	41.2	71.2
1884	Mackay-Bennett (S).	2353	350/300	6.740	26	42.0	72.3
1884	Mackay-Bennett (N).	2346	350/300	6.630	26	41.8	71.2
1894	Mackay-Bennett(3rd).	2161	500/320	4.671	40 (g)	54.6	77.2
1894	Anglo-American.	1850	650/400	2.420	47.4 (e)	47.4	47.4

(a) Report of Engineers, Messrs. Clark, Forde & Co., to the Manager of the Anglo-American Telegraph Co., dated June 25, 1877.

(b) Report of Engineers, Messrs. Clark, Forde & Co., to the Manager of the Direct United States Cable Co., dated June 25, 1877.

c) Report of the Engineer-in Chief, Mr. von Chauvin, to the Pouyer-Quertier Cable Co., dated June 15, 1880.

d) Report of Dr. Muirhead to Mr. von Chauvin, Representative in London of the Western Union Telegraph Co., dated July 10, 1883.

(i) Special trial of code words, 18 words per minute } mean 21.5
(ii) Press messages, usual rate, 25 " " "
(iii) As many as 135 letters per minute have been observed to pass at times without requiring repetition.

(e) "Electrician" dated October 12, 1894.

(g) From a letter from Mr. G. G. Ward, Vice-President and General Manager of the Commercial Cable Co., dated May 10, 1895.

Appendix No. 2.

Trans-Pacific Telegraph Cable Survey.

[*From Annual Report of Chief of the Bureau of Equipment, Navy Department, November, '99.*

A practicable route for a submarine-telegraph cable was established between San Francisco and Honolulu some years ago.

In order to continue the survey of the route from Honolulu to the Philippines, the U. S. S. *Nero*, under command of Commander Charles Belknap, U.S.N., was very thoroughly fitted out and equipped for deep sea exploration at the navy-yard, Mare Island, during the early part of the present year. The *Nero* is a large steam collier purchased for use during the late war, and on account of great steaming radius was admirably adapted to make the survey. After a careful consideration of the subject, it was decided that the best route westward from Honolulu to the Philippine Islands was by way of the Midway Islands and Guam, landing the cable at a convenient point on the east coast of Luzon as near as possible to the latitude of Manila. It was also decided as desirable to survey a route from Guam to Yokohama. Elaborate instructions for the survey were prepared. The plan of the survey, which is represented on the accompanying chart, consists in carrying direct lines of soundings, taken at alternate intervals of 10 and 2 knots, from Honolulu to the Midway Islands, thence to Guam, and thence to Luzon, and also from Guam to Japan. The return course to be pursued is a zigzag line passing back and forth to equal distances on each side of the route followed in going to the westward, with soundings at intervals of 20 knots at the turning points.

The *Nero* sailed from San Francisco for Honolulu on the 22d of April. She sailed from Honolulu to commence her work on the 6th of May. On the 22d of May she had completed a single line of soundings to the Midway Islands, by July 4 to Guam, and by August 1 to Luzon.

Along this route, which is 4,812 knots in length, 853 soundings were taken. The characteristics of the bottom soil and the temperature of the surface water were observed at each sounding station, and these, together with the meteorological record and the frequent observations of specific gravity, bottom temperature, and the currents of the ocean, besides their value in laying a submarine cable, will form an important contribution to the physics of the Pacific ocean.

Two offsets from the projected great circle route between the Midway Islands and Guam were found to be necessary in order to avoid obstacles to a successful laying and operation of a tele-

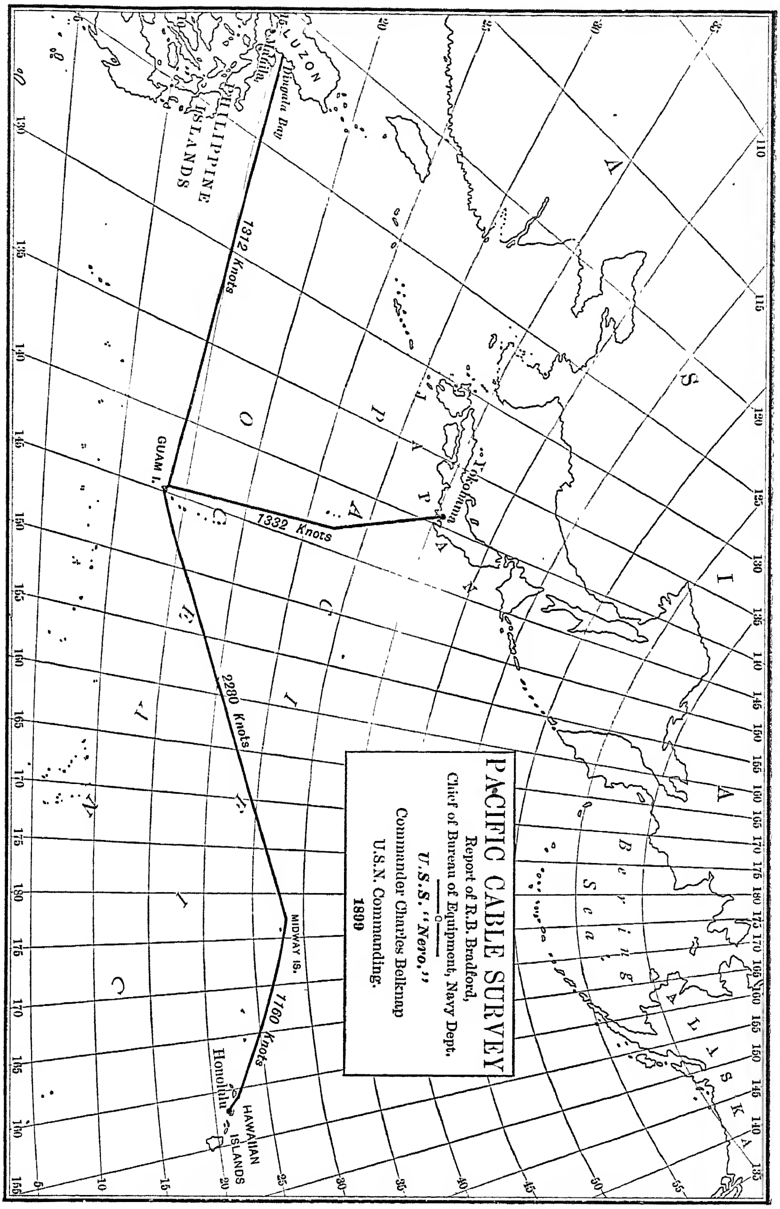
graph cable. The first of these obstacles encountered is a submarine mountain situated a short distance westward of the Midway Islands and rising from the floor of the ocean, which here sinks to a depth of 2,200 fathoms, to within 82 fathoms of the surface. The second obstacle is one of the deepest submarine abysses yet found in the world, situated about 500 miles eastward of Guam, and sinking to a depth of more than 4,900 fathoms.

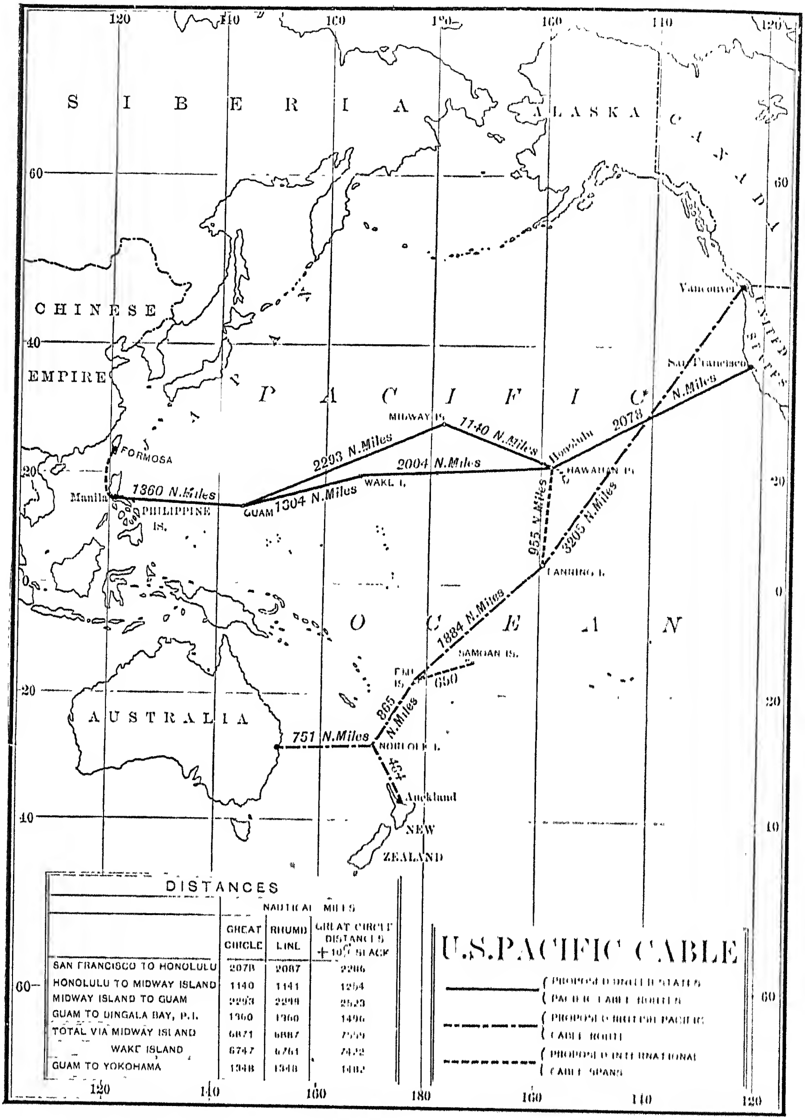
Reports have been received of the preliminary line of soundings from Honolulu to Luzon, and they indicate that the route which is being surveyed will prove entirely practicable.

No reports of the soundings taken on the return trip or of any soundings from Guam to Yokohama have been received.

Owing to illness, Commander Charles Belknap, U.S.N., was relieved from the command of the *Nero* at Manila by Lieut. Commander H. M. Hodges, U.S.N.

The expenses of this survey, so far as this Bureau is concerned, has been entirely defrayed from its current appropriations.


PACIFIC CABLE SURVEY
Report of R.B. Bradford,
Chief of Bureau of Equipment, Navy Dept.
U.S.S. "Nero,"
Commander Charles Belknap
U.S.N. Commanding.
1899
LUZON
Manila
Dingala Bay
PHILIPPINE ISLANDS
1312 Knots
GUAM I.
1332 Knots
Yokohama
2280 Knots
MIDWAY IS.
1760 Knots
HAWAIIAN ISLANDS
Honolulu
ASIA
JAPAN
PACIFIC OCEAN
Bering Sea
ALASKA


S I B E R I A
ALASKA
CANADA
CHINESE EMPIRE
PACIFIC OCEAN
FORMOSA
Manila
PHILIPPINE IS.
GUAM
WAKE I.
MIDWAY IS.
Honolulu
HAWAIIAN IS.
FANNING I.
SAMOAN IS.
FIJI IS.
NORFOLK I.
Auckland
NEW ZEALAND
AUSTRALIA
Vancouver
San Francisco
UNITED STATES
1360 N.Miles
1304 N.Miles
2293 N.Miles
2004 N.Miles
1140 N.Miles
2073
N.Miles
955 N.Miles
3205 N.Miles
1884 N.Miles
650
865 N.Miles
751 N.Miles
DISTANCES
NAUTICAL MILES
GREAT CIRCLE | RHUMB LINE | GREAT CIRCLE DISTANCES + 10% SLACK
SAN FRANCISCO TO HONOLULU 2078 2087 2286
HONOLULU TO MIDWAY ISLAND 1140 1141 1254
MIDWAY ISLAND TO GUAM 2293 2299 2523
GUAM TO DINGALA BAY, P.I. 1360 1360 1496
TOTAL VIA MIDWAY ISLAND 6871 6887 7559
WAKE ISLAND 6747 6761 7422
GUAM TO YOKOHAMA 1348 1348 1482
U.S. PACIFIC CABLE
PROPOSED UNITED STATES PACIFIC CABLE ROUTES
PROPOSED BRITISH PACIFIC CABLE ROUTE
PROPOSED INTERNATIONAL CABLE SPANS

Discussion in New York.

The President:—Gentlemen, we have listened to a very interesting paper upon a very fascinating and interesting subject, no less a subject than the only gap which exists in the electrical fence around the world, and the question as to how that gap shall be filled and who shall fill it, is one of very great importance to everybody concerned, to ourselves as electrical engineers and to the nations who dwell upon the sides of this great gap, as citizens of the world. I hope that the discussion upon this subject will be as interesting as the paper to which we have listened.

Mr. Herbert Laws Webb:—Mr. President, I have listened to Capt. Squier's paper with a very special interest, because cable-laying is my first love, and however circumstances may drift you apart, I think it is always pleasant and grateful and interesting to hear of one's first love.

I may say that I think there is very little to debate in Capt. Squier's paper except where he raises debatable points. Those occur in connection with the traffic, with the proposed working in a continuous manner. As regards the feasibility of the scheme itself, I think there is no question at all in the minds of submarine cable engineers, especially as regards the American route; and even as to the more ambitious British route, firm offers have been made to lay the whole series of cables, including the long Vancouver-Fanning section, so that it is quite evident that the most experienced engineers do not fear any difficulty, either on account of the great length of the section or on account of the great depth of water encountered. The average depth of water is rather greater than the average depth encountered in other oceans. But the improvement in the manufacture of submarine cables, the improvements more particularly in the manufacture and protection of the sheathing, and the improvement in the art of cable repairing have caused the fears that existed about ten years ago with regard to a depth of 3000 fathoms to have disappeared from the minds of practical cable men. So that as regards the feasibility of either scheme, I think we all agree with Capt. Squier that there is at present no doubt whatever. I think that the American scheme is very much the preferable one on account of it having a much shorter distance for its longest span than the British scheme. There is no doubt that the great length of 3500 miles that would be required in the section between Vancouver and Fanning would seriously limit the speed of the whole series of cables. That difficulty does not exist with the American scheme, where the longest section is something under 2500 miles—no longer than several of the present North Atlantic cables. Then I think the American scheme has the further advantage of going to the Hawaiian Islands, which is already an active center of trade and is no doubt destined to become of a great deal more importance than it is at present.

Where I rather take issue with Capt. Squier is in the proposal that the cable should be worked as a government institution. I think that practically the only argument in favor of that proposal is that the government can raise money at a lower rate of interest than a commercial company. The very amount of capital required for the Pacific cable has no doubt deterred private capital from establishing it up to the present time. There are numerous capitalists in this country who have been anxious to lay the cable; gentlemen who have had good experience in managing cable properties; but they are not quite willing to incur the entire risk, and have refrained from active measures pending some assistance from the government. But I think that as a general rule, and my experience, which extends over a few years, and into quite a number of different countries—is that the telegraphs and telephones do not flourish under government management. I am not quite sure that even the post-office, which has become by a sort of divine right a government monopoly in all countries, would not furnish us a better service if it were run by a commercial company or by commercial companies in competition. I rather think, even in this country, if commercial companies were operating the post-office service, we would get better results than five days for a letter and its reply between New York and Chicago, or three days between New York and Boston, and I think that a letter written for New York and posted in New York would sometimes be delivered in New York on the same day. If you go into other countries, in Europe—I should incline to make an exception of Great Britain, because I think the British telegraph service is about as good as you can find anywhere—but in the continental countries I think that the government management of both telephones and telegraphs does not give as good results as company management, which still exists as regards telephones in one or two countries of Europe, and, strangely enough, which exists in one country as regards the post-office. It was rather a surprise to me to find only a few months ago in a country where the government is most rigid in its monopoly of means of communication, that there was a company operating a post-office in some of the biggest cities. In Berlin, and I believe in Hamburg, there is a company running a post-office service for the local delivery of letters in competition with the Imperial post-office, charging lower rates and furnishing a more rapid service, and the Imperial post-office feels the competition of this company so much that it has taken measures to buy it out, and is offering to lower the rates of postage for local letters in the large cities, if it obtains a complete monopoly of the post-office business.

Now when it comes to the proposal of operating a cable continuously, of providing such rates as to attract a sufficient amount of traffic to fill up the cable the entire time—Capt.

Squier reckoned on a traffic of some five million words a year each way—I think he overlooks two or three characteristic points of cable traffic. He evidently counts, by his comparison with the mails, on attracting a large amount of purely personal, private messages. Now I think it may be taken almost as an axiom that the urgency of private communications varies inversely as the distance that you are apart. Private messages as a rule, private telegrams, refer either to making appointments or to breaking appointments or to making excuses for not keeping appointments. They are generally addressed by people who are close together, who are in the same country, within a few miles of each other, or in the same city. I think the large majority of private telegraph messages are caused by the people who send them having to meet shortly, or having met shortly before, or not having been able to meet; the message of congratulation and similar communications probably make up a very small proportion of the total number of private telegrams. Now it seems to me that when you get away, when you are separated by the sea, there is very little occasion to send urgent private messages. As a rule, the urgent private messages that go by cable are on matters of life and death; you would send those anyhow, no matter what the cost was, and I don't think a lowering of the rate will induce any very large increase of private messages. You cannot imagine the ordinary letters that people write to each other when they are separated by the sea being condensed in any possible manner so as to go in a cablegram. I happen to have relatives all over the world and it seldom occurs to me to write at all to the most distant ones, and certainly it never would occur to me to send them a telegram at any price. That is my experience and I think it is largely that of others.

Then I think it is overlooked in this proposition that the great difference in time between places separated longitudinally by the oceans causes even business messages not to be of great urgency as regards *hours*. If I am in an office say in New York and get a telegram from London requiring a reply, if that comes in in the middle of the day it makes no practical difference whether I send the reply during the remainder of the working day or at night, because it is already four or five o'clock in the afternoon in London, and it makes no practical difference whether they receive a business telegram at that hour in the afternoon or the next morning. So that if there was a night rate, a lower rate during the night, I think the majority of business telegrams would be kept for that night rate, and that would of course apply very much more in the case of a Pacific cable, where the difference of time is much greater. Between New York and Manila the difference of time is eleven hours, so that what is our night is practically their day and if there were a night rate it would simply mean that all the business messages which have to go anyhow would go at night, instead of going in the day. I

think that is the reason why no night rate has ever been instituted by the Atlantic cables. You could not have a finer opportunity for experimenting with rates and adopting differential rates than in the Atlantic cables. There are practically no two countries in the world where private and social relations are so intimate as between England and America and there are probably no two countries where the business relations are so close, and it seems to me if it were possible to differentiate the rates other than by the ordinary difference between press and business messages and government messages, if it were possible to introduce a night rate for purely private messages which would yield a profitable result I think it would have been done already.

Mr. T. E. Hughes :—There is one question I would like to ask Capt. Squier in connection with his suggestion of having a connection between the proposed British cable and the proposed American cable, what influence would it have on the operation of the American cable if the English cable be under government contro- and the American cable under the control of a corporation? It occurs to me that there is a point there that is decidedly in favor of American government control. For instance, if there should be any difficulty between the nations in the far east, they might arbitrarily exclude American messages; but if by treaty our business could be switched around on the English cable a condition would arise to protect our interests, while under a commercial control such condition could not exist.

Again, the gentleman who has just addressed us takes up the discussion of a differential rate. While possibly his remarks apply in so far as a night rate and a day rate may exist, yet taking our business with our extreme Pacific possessions—the Philippines—where we are under a two-weeks' delay or in other words two weeks to reach them other than by cable, it occurs to me that a sliding scale would operate decidedly in favor of the operation of the cable. In other words a cablegram to be delivered to Manila subject to delay of one, two, three, four, or even five days could be transmitted at a mere nominal cost as compared with the instantaneous delivery and still make a ten day issue in favor of the use of the cable.

Another point arises as to whether there is any data extant as to what revenue could be anticipated on operating an American cable as to its commercial revenue as compared with what we know (and the author has so exhaustively given us) the United States government is to-day paying. In other words what percentage of the entire amount of business being done with our Philippine possessions, does that represent? If the government's contribution is fifty per cent., of course we can see that the net revenue to a commercial corporation, or the

government itself, would be double. I am interested as to whether such data is available.

CAPT. SQUIER:—In answer to Mr. Hughes' remarks I will say in regard to the other data that it has been a great deal of trouble to get this data together and we have written to the press all over the country a circular letter asking them to give us an account of their Philippine business. We know what rate they pay. I have not given it, purposely in this article, because I do not care to at this time. We asked them provided they are at perfect liberty to do so, to furnish us with information of what their cable bills are monthly for the last six or seven months. As I say, it is difficult to get this together and unfortunately now I have not it at hand. It is coming in gradually and we hope to have something before very long —not what will be done but what is being done now. We know what the government is paying. It is paying approximately a thousand dollars a day in cash to foreign corporations for messages. There is no question about that, for we have counted the words. We also know that the short span of cable about six hundred miles long from Hong Kong to Manila, the cost of which could not have been more than half a million dollars, is now earning seventy-five cents a word for every word that goes over it, and that is three times the rate to Europe, and is the interest on three and a half million dollars, enough to lay a whole Atlantic cable. This company had from Spain a cable right to land in the Philippine Islands, and that is the price they are exacting now. The other data, I am sorry to say, is not in hand, and the general data that I gave, $150 a mile is taken from the average earning power of all the long cables of the world. I believe that to be a very low estimate. I have merely given it for what it is worth. I have no doubt, from what I can learn, that this enterprise will be a paying enterprise from the very beginning, and particularly if it is a government enterprise, because the government can do it cheaper than any one else. It can borrow money cheaper, and is not required to earn any dividends at all, simply earn the interest on the money and keep the plant maintained as a permanent asset, making prudent provision for a sinking fund, which I have endeavored to make here in this table given on page 659.

In regard to the other points that were brought up—in regard to differential rates, I have been unable to come to any other reasonable conclusion than the one that a cable, particularly a Pacific cable, should be operated all the time. I cannot see any reason for not operating continuously, for the reasons which I have given in this paper, that the operators sit there, and it practically costs nothing more to maintain it than if you did not operate it. You have to keep the cable ships, etc. The cable does not deteriorate by sending messages, and it does not harm it in the least. If the cable is idle for an hour, it is an absolute loss

to the world. I would say, send to the press for nothing rather than allow it to be idle. It is a case of a ten million dollar plant idle for four or five hours in the day, when it doesn't cost any more to use it than it does not to use it. But if it is a government enterprise, with all of our soldiers in the Philippines, and people blockading Washington to get information, if there are any idle periods, I am sure they could be used to advantage to communicate with the Philippines. It is really pathetic to witness the large amount that is charged to send a few words to the Philippine Islands, which is now being filled up with our relatives and friends, whom we wish to communicate with. I remember one particular instance, in the last day or two, where, at the end of four days, a father had spent something like $100 to find out whether a bullet had gone through his son's body or not. This is an actual case, and such cases are occurring now all the time, and the rates are prohibitive and absolutely limit the kind of traffic. The difference of time between the countries that has been mentioned—of course, that is understood very well. It is well known on any long cable, but you have such a leeway in the time. Your only competitor is a mail ship, which requires two or three weeks, and the objection that patrons would all take the night rate, or the cheap rate, seems to me erroneous.

Of course when you attempt to establish a series of differential rates, as indicated, you would probably first get it wrong. You might guess at it, and say for class No. 2 the rate will be half what the maximum rate is. You might allow on the back of the blank, three or four hours for delivery. In other words, readjust the rates frequently until you find out what is the exact schedule of rates that would fill the cable continuously. Such a series of rates would be easily found. We might even classify traffic into ten or twelve different classes, if necessary. We have now four classes in the mail matter on the steam train between here and San Francisco. If we have a single thread between here and another hemisphere, I cannot see why we should ever let it be idle at all. I cannot see any reason why it should not be used continuously, because you can classify the business in as many classes as experience indicates is necessary. You might have a right-of-way rate, which would be the very highest rate, when a man wants his message to go at once, and the next rate might be very close to that rate. If you find that they are all taking this second rate, you would simply move it up so near the first that they would not find it sufficiently advantageous; so that I should think that four, or five, or six different rates could be adopted, and the last would involve say a week's delay. Classify all traffic, and when slack time comes send them in their order. It simply uses those idle hours that are no use to any one at present, and costs nothing except the price of the operating clerks, which, as I have shown, is an inconsiderable amount of the total annual

expense of the plant. You simply require an insignificant expense to use a ten or twelve million dollar plant. From a business standpoint, it is a most unique set of circumstances. In a manufacturing plant you cannot run at all times, because the plant wears out, and the coal bill is too large, and you have to engage too many more employees. Referring to the Atlantic cables—they are not now operated continuously, but I believe they soon will be. I think the reason that this policy has not already been adopted in the Atlantic is because of the peculiar character of the cable business, and the peculiar history of ocean cabling. Fifty years ago it took a good deal of confidence to invest any money in cable business. It was a very hazardous matter, and rates had to be very high. It is not easy for an Atlantic cable company now to do anything suddenly, even if it wants to. They are bound up with their competitors in mutual moral obligations, besides legal ones. But in the new field of the Pacific, if the cable is run by the government, it can advance and treat every one fairly. Treat the land systems perfectly equitably. That is, turn over unrouted messages to them in an equitable proportion. Have no favor shown any institution, individual, or corporation, or any other person, and a government enterprise, is the only solution I can see to prevent the extension of present monopolies, because any cable system must have traffic arrangements with a land system. A cable is useless without a land system at each end, covering the territory that the cable is to serve. Therefore take the example of the Pacific. Suppose it is laid by a private corporation. That corporation is immediately obliged to form some relation with particular land systems. The other land lines are, of course, excluded and out of this arrangement; so that what happens is that land companies combine with the cable, just as it is now—enlarging the present state of affairs into a larger organization, which keeps rates so high. So that I see no wise solution, except to put the cable down in a fair open field by the government, treating everybody alike and running the cable simply to maintain American commerce itself, not to earn dividends. I believe a Pacific cable will lower the through rates, and it will probably lower the Atlantic cable rates also, because, as I could have shown you, the present rate now between Europe and the east, via the Great Northern and Japan, is about \$1.50, as I remember, and over the southern route, by the Eastern and China, is something like \$1.90. It is in evidence before the British Commission that the Canadian Pacific Railway has agreed to lay down messages in Vancouver from London over the Atlantic cables for 25 cents. Therefore it can be assumed that we can put English messages in San Francisco for 25 cents on the through-rate plan, so that if we can put the cable part of the message at 75 cents, we would make a \$1 rate or \$1.25 rate, at most, between London and Japan, which will either cause the eastern rate to be lowered or else divert the European

traffic over the Atlantic cable system. That is why I made the statement that if this cable is put down and run by the government, I think it will operate to readjust the through tariff rates from the east, because the new route has long spans, few transmissions, and few chances for error, and you cannot compete with it.

About ten or twelve years ago all mails used to go east. Finally they were diverted west, and the through mails cross the American continent, in a large proportion. There are two ways around the world, and it is a great advantage to have a competitive route both ways. Up to the present there has been only one way, telegraphically. By putting this last link in, it is going to make a greater difference than any other single telegraph line ever did, because it is going to join each point by two routes.

In regard to the differential rates, I am glad to hear the opinions that have been expressed. I have asked a good many of the Atlantic cable experts why they do not work the cables continuously. It seems a sin to leave a several-million-dollar plant idle, when it costs nothing extra to use it. They might give it to the newspapers, so that we could learn something about these countries over there.

I really cannot come to any other conclusion. The difference of time does not enter at all, because you classify everything, and when the cable becomes idle, put in class No. 2, or No. 3, or whatever it is, according to its class.

I would be glad to hear other views in the matter—it is a conclusion that I cannot see a flaw in.

The President:—The subject, of course, has two distinct sides: The engineering side and the commercial side. I think as engineers we all agree that the cable can be laid; it is only a question of how much it costs. We all agree that if one cable cannot be kept working that with duplicate cables the system can be kept working. In any case we should have in a certain sense a duplicate cable on the other side of the world. So that from an engineering standpoint there is no difference of opinion at all between us except in regard to minute details, as to the question of cost, as to question of size of the cables, and as to the best positions in which those cables could be laid. When we come, however to the question of the commercial aspect, we get differences of opinion. This aspect of the question has, however, been more thoroughly and more practically studied than even the engineering aspect of the question, because it has come home to every manager and every administrator of submarine cables and of long telegraph lines ever since cables and land lines have been initiated.

There can be no doubt, I suppose, as a broad proposition, that a government can raise money on better terms than any individual or association of individuals, because its credit is better; and moreover a government can also afford to make experiments

upon rates better than any individual or collection of individuals owning a telegraph or telephone scheme. At the present time when a corporation, as is usually the case, owns the cable, it has no object, primarily, in making high rates. It has an object in getting a dividend, and its only object in placing the rates high is to enable dividends to be secured. But it would be just as well content in cutting those rates in half or reducing them to any desired amount if thereby it could ensure the necessary dividends to its stockholders. And it is a matter of experience that as you lower rates you do not get a corresponding return from the traffic to make up for the diminution. Eventually, after the public had been educated up to it I suppose that you would and must, perhaps, according to logic; but it takes time before the public can be educated to the greater facility, and to the use which an increased facility places at their command; so that if they have only to spend half as much money per word, to teach them to spend twice as many words. No doubt it would come in time. But during that time the dividends of the stockholders are falling off and the cry is to the managers " This thing must not be. You must put the rates up again," and the rates go up.

Now when the government owns a system it is possible, of course, for them to say, "Wait a while; we will educate the people up. We can afford to wait until we have educated them up." And in that way there is, perhaps, a signal advantage in government control of cables and long telegraph systems. But otherwise I quite agree with Mr. Webb that upon the broad principles of finance and competition, private ownership is preferable. I think that the plan of filling the cable with traffic as Capt. Squier suggests, while it is eminently proper—is rather more utopian than practical. In the first place there are many cables at the present time, long cables, that are busy day and night. I do not allude particularly to the Atlantic cables, because the condition of traffic, the ebb and flow of business between the two sides of the Atlantic is such as determines the rushes and periods of relaxation. But take the cable system of the world as a whole, and I know some cables where the operators do not stop except for relief. There may be exceptions occasionally, and, of course, Sundays are usually slack days; but I think it unsafe to say that long cables at the present time remain idle.

Then, if you are going to experiment down to the point at which you are going to fill your cable up on working days, on Mondays, Tuesdays and Wednesdays, on Saturdays when a foot ball game occurs you will be so crowded that you will not get clear for a month, and it is necessary to keep your traffic in hand so as to keep leeway as a reserve for rushes.

From a standpoint of general policy, no doubt Capt. Squier's position is right. The proper way to operate a cable is, theo-

retically, to keep it fully occupied with traffic. Theoretically he is right, that we should have low rates and learn to send all our messages at any time, private or public, that way. It is a matter of habit, and it is a matter of cost. If it were cheap enough we would all send our letters that way, no doubt. It would take a little time to learn how to do it. The difficulty has been that at existing rates if you lower them you cannot make a dividend. If the government is going to give a helping and educational hand we would all be benefited to that extent.

Dr. M. I. Pupin:—Mr. President, I am rather surprised, that in view of the fact of our having discussed here last month the possibilities of wireless telegraphy, that nobody should have mentioned this evening the possibility of settling this whole cable question by wireless telegraphy. You know that there is a great deal of discussion in the newspapers about the Western Union getting a permanent cable monopoly to Cuba. It seems to me that the Western Union having a cable monopoly to Cuba, suppose you arrange to telegraph from Key West to Havana which is only about 90 miles; by wireless telegraphy, you would get around it. I think you could telegraph just as fast by that means as you can telegraph by a cable. It is simply a question of a little bit of work, a little bit of experimental refinement. I have but little doubt after thinking over this matter, that before long we shall be able to telegraph by wireless telegraphy over 1500 miles. Now if you can do that—I say if you can—just think of the possible changes in communicating between continents. This wireless telegraph is only in its infancy and it seems to be a very vigorous infant—growing very rapidly.

There is a distance of about 2400 miles between San Francisco and Honolulu. There you would have a relay station; another relay station between Honolulu and the other island, and for the rest you can do it without relay stations. Now Capt. Squier proposes two cable ships; one at the Philippine Islands and one at San Francisco or at Honolulu. Why not use these cable ships as relay ships. It seems to me that 1500 miles for wireless telegraphy is nothing so very serious. I think it was in view of the fact that wireless telegraphy is going to be a very important factor, and growing so rapidly, that it is quite proper for me to mention the bringing of wireless telegraphy into this very problem.

Mr. J. H. Hallberg:—I read with much interest a short article in the *Western Electrician* of December 23d, 1899, which seems to further assure us of the possibility of long distance wireless telegraphy. It is claimed in the article, that Prof. Reginald A. Fessenden and his assistant, Prof. Kintner, in the electrical laboratory of the Western University of Pennsylvania, have produced a receiver for space telegraphy, which is two thousand times more sensitive than the coherer of the Marconi system.

Dr. Pupin:—Two thousand times?

Mr. Hallberg :—Yes, two thousand times. And, it was further stated that it may be possible to send messages, through the medium of this improved instrument, across the Atlantic, with poles less than 200 feet high.

Capt. Squier :—I might say that that is just what the government is now considering for service between Key West and Cuba, also between Cuba and Hayti, across the Windward passage, and then across the Mona passage to Puerto Rico.

Mr. Hughes :—If the President will excuse me, there is one more point. Has the author made any computation as to what amount of time is consumed in sending the one thousand dollars a day messages on our Pacific business, in minutes or hours? We are spending a thousand dollars a day on our Pacific telegrams; how many hours or minutes does that consume?

Capt. Squier :—I don't know how long they take to send them.

Mr. Hughes :—I would say off hand, from rough figuring that probably it does not represent more than an hour a day. Allowing margin then of an increasing business of twenty to one, we then have four hours left for the influx of an abnormal increase in business. Consequently it seems to me that is a very vital point on the part of the author that we have a ten million dollar plant there that we operate only one twenty-fourth of its working capacity. If we reduce our rates to a commercial basis which will admit of an increase of twenty to one, we still then have one-fifth of the working capacity of the cables left for an influx of increased business on the part of the government or otherwise, which proves, I think, very conclusively that a differential rate of tolls of traffic is one of the strongest points in favor of the government operating that business. The government can demonstrate just exactly what would be the correct ratio as to the sliding scale, and it would represent an enormous revenue to a commercial corporation to protect themselves to prove the case before it is practically demonstrated. It very forcibly shows that the government is the only one that can take the Pacific cable and work out the problem that is yet unsolved.

[Adjourned.]

[Communicated, After Adjournment, by Mr. Herbert Laws Webb.]

As the discussion on Capt, Squier's paper reached into rather late hours, I submit a few further remarks in writing. I am by no means an opponent of low rates, but I do not believe that under normal conditions any possible rate would tempt the traffic that Capt. Squier reckons with. To consider the traffic that occurs during the existence of war as bearing on the results obtainable year in and year out in the commercial working of a long cable is like gauging the yearly traffic of the Broadway cars and the elevated railway from the traffic of New Year's Eve, when tens of thousands of people set out to drown the chimes of

Trinity Church, that on other nights of the year never even think of a church. In war time neither government departments, enterprising newspapers, nor private individuals having relatives at the front, count the cost of cabling. But in the piping times of peace, government, private and press messages, collectively, count for a very small proportion of the total traffic of long cables. That traffic is made up almost entirely of business messages, and under any arrangement of rates the character of that traffic will not change to any appreciable extent, for the simple reason that no steady demand for cable communication comes from any other than purely business sources.. Business messages will go over cables no matter what the rates, and when rates are lowered more business messages will go, but only a certain amount more, because the supply even of business messages is limited. As was pointed out by the President, it has been found in certain cases that rates could be lowered too far—that the traffic did not respond to the cheaper rates.

Capt. Squier seems to have misinterpreted my reference to the effect on the traffic of the difference in time between places joined by long cables. The difference in time has the effect of making the majority of business messages non-urgent, as regards *hours*. For one hour in the day the stock exchanges in New York and in London are open together, and that results in a flow of messages for a few hours in the day that are urgent as to *minutes*, and produces what is probably the quickest telegraph service between any two points on the globe. But with the majority of business messages there is no such extreme urgency. Many business telegrams, in the ordinary course of affairs, are sent from New York in the afternoon, that is, after business hours in London, and are delivered in London either late at night or the next day. If there were a night rate, or any sort of deferred rate, these messages would be held until night, to secure the lower rate, and would be just as efficacious as they now are at the full rate. Between America and the Philippines the case is still stronger. There is no stock-exchange traffic, and by reason of the greater distance, the infrequency of mail departures and the complete separation of business hours, not one message in a thousand would be urgent as to hours, and practically the whole traffic would avail itself of a night rate, or of any sort of deferred rate that might be instituted. The mails between New York and the Philippines vary from four to six weeks in transit, so that even the preposterous suggestion of cablegrams marked to be delivered in three days would suit the purposes of a large proportion of business messages. No cable manager would want to have anything to do with classes of messages to be delivered in one, two or three days from the date of origin. Such messages would cause more trouble and confusion than twice the number dealt with in the ordinary way. But there is no doubt that even a three-day-on-the-way cablegram between points six weeks apart

by mail would serve the purpose of much of the present traffic, and a cheaper rate for such a service would simply have the effect of diverting a certain amount of traffic that would ordinarily pay the full rate into the three-day-delay class.

There are many things for which a certain and steady demand exists, but for which a very large demand could not be forced, even if prices were reduced to practically nothing. A wide-spread demand cannot be created for that for which the majority of people have no use, even if you offer to give it away. In the words of a famous American, it is a condition and not a theory that will confront the management of the Pacific cable, and in spite of the keen interest at present taken in Philippine affairs, that condition will not differ in the long run from those that govern the operation of other long cables.

[COMMUNICATED BY M. I. PUPIN IN REPLY TO PROF. FRANKLIN.]

[See page 651.]

Professor Franklin quotes four erroneous statements in my discussion. I shall consider these in order of importance, beginning with the least important. "The electrical oscillations," says Professor Franklin, "of a conducting staff perpendicular to an infinite plane are precisely the same as the oscillations of an isolated staff of double length. Dr. Pupin would have it appear that the staff and plane is a distinct and much more complicated oscillating system."

This is a very sweeping statement and should be backed up by a reference to the authorities on which it rests. Besides the oscillatory system which I discussed is not correctly stated by the Professor. It is an infinite horizontal conducting plane with a vertical staff forming a part of it, *then an air-gap*, and then another vertical staff. The air-gap is the center of disturbance. If the learned Professor means that the oscillations on such a system are the same as on an isolated wire consisting of the vertical staffs above the horizontal plane plus two other vertical staffs below the horizontal plane of the same length as the two staffs above the plane, then, in my humble opinion, he is wrong. If he does not mean that, then I fail to see the point of his criticism.

"In the second place," says Professor Franklin, "the use of successive impulses in the sending circuit for increasing the oscillation in receiving circuit does, as it seems to me, require each successive impulse to be in proper step with the foregoing impulse as pointed out by Mr. Mailloux. To realize this condition in practice would be next to impossible and it means to me that we must * * * ."

It is evident that the resultant of two waves is greater than any one of the two components unless the difference in phase between them is considerably greater than a quarter of one period. Now a simple consideration will show that if we communicate to a conductor several series of waves, these series succeeding each other at equal intervals of time, that the waves thus set up in the conductor will continually approach the incoming waves in phase. In fact the phase equality will be reached very rapidly. But in order that the waves already set up in the receiving conductor should be aiding the incoming waves in phase equality is not at all necessary. All that is required is a phase difference smaller than a quarter period. This tendency of the waves set up in the receiving wire to get into step with the incoming waves may be called the accommodation of phase and may be easily demonstrated by a few simple force parallelograms.

"In the fourth place," to quote again Professor Franklin, "it does not seem that small logarithmic decrement is of any importance in determining the range of signaling. * * * ."

Well, I am not aware that I ever said that it was. Why then, accuse me of an offence of which I am not guilty. All the virtues I claimed for waves of small decrement is a power of producing strong resonance and, therefore, selectivity.

I come now to the last offence which is charged against me. "In the first place," says Professor Franklin, "he would have it appear that the logarithmic decrement depends mainly upon the resistance of the respective circuits, while it is well established theoretically that the dissipation of energy by radiation is much more prominent in determining the decrement of electrical oscillations except in those types of oscillators which do not radiate to any great extent. * * * ."

Unless I am much mistaken, Professor Franklin is evidently mixing up things which do not belong together. That which is well established theoretically is simply this: If electrical oscillations are set up in a particular way in certain conductors like a sphere or a short cylinder then the damping due to radiation is very much greater than that due to the heat losses produced by the ohmic resistance of the material of which the oscillators are made. The two particular ways of excitation which the theory succeeded in solving are these: (*a*) Sudden destruction of an electric field, (*b*) sudden destruction of a magnetic field in which the oscillators are placed. These two ways of starting electrical oscillations are entirely different from the way in which electrical oscillations are set up in the case before us. Here a higher difference of potential is established between two parts of the oscillator, the two parts being separated by an air-space. A breaking-down of the air-gap starts the oscillations and the air-gap itself becomes a part of the oscillator. We have here a heterogeneous oscillator, one part of which possesses a very high resistance. Mathematical theory has not succeeded yet in deciding how much of the damping in a case of this kind is due to radiation and how much to ohmic resistance. It should be observed now that this matter will depend much on the frequency of oscillation. The higher the frequency the more prominent becomes the damping due to radiation. I have not the slightest doubt that with low frequencies such as are employed in wireless telegraphy and where an air-gap of a good fraction of an inch is employed, most of the damping is due to the resistance of the air-gap. The matter is capable of experimental test. Take two long rods, place them vertically and through the air-gap between them pass sparks. At a distance take two equal rods and make the air-gap between them minute. See now whether you get better inductive effects with a large or with a small primary gap.

According to Professor Franklin, the inductive effects should be proportional to the square of the spark length. That such is not the case is shown by Professor Fessenden. If the receiving rods are carefully tuned it would be found that the

inductive effects, even with short rods, say twenty feet, where the frequency is very much higher than the one employed in wireless telegraphy are often even better with short sparks than with long ones. This would certainly be impossible if the damping is due principally to radiation. Why, Marconi himself prefers sparks of quite moderate length to long ones. Now if the damping is due principally to radiation why not employ long sparks?

I will state here, however, that in an arrangement like the two vertical wires used for transmitting in wireless telegraphy the principal part of the energy radiated off leaves, in all probability, the transmitting wire during the first half-oscillation immediately following the spark, and the rate of radiation during this interval is entirely different from the rate which attains after the first half-oscillation. I came to this conclusion sometime ago, after the date at which this subject was discussed before the INSTITUTE. I do not think that it will be well to discuss this matter at present. Suffice it to state that this damping due to this initial radiation is an entirely different story from the damping which accompanies the stationary state of oscillations and which Professor Franklin has in mind.

SAMUEL DANA GREENE.

Died January 8th, 1900.

Samuel Dana Greene and his wife were drowned while skating on the Mohawk, late in the afternoon of Monday, January 8th, 1900. They had started to skate at dusk; there was a strong wind blowing, which suggested the use of a skate sail, and when last seen alive they were skating rapidly down the river with the sail. Their bodies were found in the open water near Freeman's Bridge. There is little doubt that owing to the very rapid rate at which they were going, they were unable to stop themselves when they saw the open strip of water in front. Cries for help were heard, and assistance soon arrived, but the rescuers having no appliance at hand for getting at the bodies, which were some distance from the solid ice, valuable time was lost in returning to the shore for these. The body of Mrs. Greene was first recovered; she was still breathing, but all efforts to revive her failed. The search for the body of Mr. Greene was continued down the river for an hour or more, without success. The searchers finally returned to the spot where his wife's body had been found, and there found the other. The position of his body and the markings on his gloves indicated that Mr. Greene had stood upright on the bottom of the river, holding his wife's feet in his hands, and keeping her above water as long as possible. This incident was characteristic of the man.

The funeral took place at Schenectady on the 11th of January. There was a short service and prayer at the house, after which the bodies were taken to St. George's Episcopal Church, escorted by Company E, Second Regiment, and a detachment of the First Naval Battalion, under Lieut. Andrews. The services at the Church were conducted by the Rt. Rev. William Croswell Doane, Bishop of Albany. The pall-bearers were Mr. Greene's intimate friends of the General Electric Company and the Naval Militia. The Governor of New York and a number of his staff were

present. All business in the city was suspended for the day. After the services, the bodies were taken to Bristol, R. I., where the interment occurred the next day.

S. Dana Greene was the son of the late Commander S. Dana Greene, who was the executive of the *Monitor* in her fight with the *Virginia*, at Hampton Roads, and who succeeded to the command after Lieutenant Worden was disabled, shortly after the commencement of the engagement. He came of a family which had been distinguished in the history of Connecticut from the time of the earliest settlement, and of which various members had been in public service at all times down to the present, as officers of the army, navy, and in executive positions.

He was born on October 24th, 1864, and consequently was 35 years old at the time of his death. Entering the U. S. Naval Academy in 1879, during the entire four years there he stood at the head of his class, and graduated number one in a class which had started with more than 100 members, but of whom only 40 succeeded in graduating. His career at the Academy was a notably successful one; even then he attracted the attention of his superiors, many of whom then predicted that his record would be one worthy of his distinguished ancestry. After graduation, July 1st, 1883, and two years' sea duty, he was commissioned an ensign. Obtaining leave of absence, he entered the Sprague Electric Railway and Motor Company, in 1887, and resigned from the Navy the following year. He did this against the advice of Mr. Sprague, who was of the opinion that he would probably regret leaving the service, though such a regret was subsequently never expressed to the knowledge of his friends. He immediately became very active in the engineering department of the Sprague Railway Company, of which he became chief engineer in 1888. About the first work undertaken was the equipment and operation of some storage-battery cars in Boston, in 1887; shortly after this he was transferred to Richmond, and was in charge of the extremely arduous construction of the first Richmond road. Since that time he has been connected continuously with the corporations which have succeeded the Sprague Electric Railway and Motor Company—that is, the Edison General Electric Company and the General Electric Company. His progress has been one of steady promotion from the beginning; in each new position he developed new qualities, which made his services of greater and greater value. At the time of his death he was the General Sales

Manager of the General Electric Company. The important work of the company in all departments, relating to sales and contracts, passed through his hands. His friends confidently expected that he would become, in the course of time, the chief executive officer of that company, if he elected to remain in it.

As was to be expected from the traditions of his family and his own education, Mr. Greene continued to take a great interest in the Naval service. He was one of the earliest and most active in the formation of the New York Naval Reserve, having risen in this service to the rank of Lieutenant-Commander, his grade at the time of his death. During the Spanish-American War, Mr. Greene served as executive officer of the "Yankee," to which vessel the New York Naval Reserve was assigned, under the command of Captain Brownson. At the close of the war he was appointed Naval Attache on Governor Roosevelt's staff.

Mr. Greene married in June, 1896, Cornelia Chandler, the daughter of Rear-Admiral Ralph Chandler. This marriage occurring only a few years ago, was the termination of a love affair dating back to the time of his leaving the Naval Academy. Their married life was a peculiarly happy one, and their home one to which it was a pleasure to go.

Mr. Greene's work since leaving the old Sprague Motor Company has been more that of an executive than of an engineer. He has, however, always taken a deep interest in electrical engineering questions, and has found time to contribute a number of papers on engineering topics, particularly those connected with naval matters. He has read several papers before the Institute of Naval Architects, and others before the New York Electrical Society and the AMERICAN INSTITUTE OF ELECTRICAL ENGINEERS. He joined the AMERICAN INSTITUTE OF ELECTRICAL ENGINEERS in 1893, and was one of its managers at the time of his death. He at all times showed a strong and intelligent interest in the affairs of the engineering fraternity. He has recently served most efficiently as a member of the Committee on National Electrical Code, and was largely responsible for the recent action which has been taken by the fire insurance bodies on the subject of grounding. He was a man of a kind which is, unfortunately, rare—one who combined careful and correct fundamental notions of engineering methods with strong common-sense and a great executive ability. He was not a great engineer, and never professed to be such; but his knowledge of the principles of all engineering matters was very extensive and sound.

The estimation in which he was held by those who knew him is well shown by the following testimonials, which have appeared in print since his death :

" His place in the class of naval cadets at Annapolis, to which he belonged, was so high that he might with confidence have looked forward to the highest preferment in a service to which he was devoted, yet he manfully gave up his chance of being an admiral because he could not see his way to remaining in the Navy without encroachiug upon his mother's slender income. In after life, when he had become a successful business man, he always cherished the earliest object of his awakened ambition, though he never openly expressed regret that he had followed what seemed to him to be the path of duty.

" In his business carreer he climbed the ladder of promotion by self-denying, diligent and honorable service, respecting himself, respecting his employers, and respecting the work which fell to his hands to do. In his intercourse with his official superiors, equals and subordinates, as well as with his customers and the outside world, he was tactful but truthful; reserved but sincere; often cordial but never familiar; prompt, energetic, and accurate in discharging his multitudinous duties.

" To find his attitude on any given question which might arise, one had only to determine what would be the view of a tolerant, impartial and honorable spectator—his zealousness for his company's advancement never betrayed him into sharp practice, he gained universal esteem by his uprightness, and held it by his serenity.

" To this man, at the early age of 35, had come a splendid position in the business world, official recognition of his energy and ability as a volunteer defender of the state and nation, ample means and a charming home, in which was enshrined a woman in every way worthy of him. To-day they seem ' but as yesterday when it has passed, and as a watch in the night.'

" Yet their lives, and more conspicuously his, are full of encouragement and fruits. In these days, when men so often consent to lower their standard of business integrity for the sake of gain, it is well to bear in mind that S. Dana Greene has left his chosen vocation in life at the call of duty and achieved success, and some measure of fame in necessity's field with ideals intact and with untarnished honor."

" Mr. Greene was a strong man, and full of mental and physical energy. He was keenly and continuously interested in everybody and everything. He was a broad and generous-minded man, and seemed to remember people because of something pleasant and wholesome that he knew about them. He remembered things because he saw something in them that could be utilized in the direction of general advancement. Anything new appealed to him instantly, and he was quick to take it up, if it showed

merit. At the same time his judgment and conservatism were of a high order, and he was equally prompt in dropping a useless idea. At the head of a large body of men, he set an example of industry and application to duty that was an incentive to all. No one appealed to him with any problem in vain. With a temperament that was exceedingly even and kind, full of helpfulness and hopefulness, he was one of the most companionable, sympathetic and lovable of men. He occupied a position in the General Electric Company and in the friendship and interest of central-station managers all over the country that was unique, and can never be filled by any other man. To those who have known him for a half-score of years, his death is a personal affliction. Such friends can but be filled with inexpressible grief."

"Lieutenant Greene was one of the most lovable characters I ever met in my life. He was always a stanch and true friend, and while a strict disciplinarian, he always knew how to acquire the love and regard of his associates and of all under his direction. The electrical fraternity has lost in him one of its most prominent members."

"Throughout the electrical field the personal and business popularity of Mr. Greene was remarkable. Uniting with the most perfect integrity in business matters, a cordial manner and a personal charm, which endeared him to his associates, Mr. Greene represented the highest type of the young American man of affairs. His untimely death will cause sincere and widespread regret in all departments of the wide field with which he was so prominently identified. To his business associates, Mr. Greene's death is a great and irreparable loss."

"He bore worthily a name of historic association. Both his father and grandfather rendered to their country distinguished service in the war for the Union. By descent and by nature he came to that nobility that imposes obligation rather than confers privilege, and he was ready and constant in the recognition of the obligation. Graduating at the head of his class at the Naval Academy, he decided against the pursuit of his profession in times of peace, but was prompt to offer his services in time of war, and he gave much time and attention to the development of the State Naval Reserve. His scientific and administrative abilities secured for him a career of great promise in the business in which he was engaged, but his interest never flagged in matters of public concern, for which his training prepared him. Any emergency would surely have found him ready. Cut off in the prime of his young manhood, under circumstances peculiarly distressing, his loss will be widely and sincerely regretted."

C. T. H.

NEW YORK, February 23d, 1900.

ALEXANDER STRATTON.

Born November 14th, 1872.
Died October 30th, 1899.

ALEXANDER STRATTON was born in New York City, on November 14th, 1872, and was educated in the public schools, taking a full mechanical course in the College of the City of New York, graduating in 1892. He took a post-graduate course in electrical engineering at Columbia University, graduating in 1894. He was elected an Associate Member of the INSTITUTE, March 20th, 1895.

After graduation, he spent two years with the Crocker-Wheeler Company, at their works, in Ampere, N. J., and in 1896, entered the employ of the "C and C" Electric Co, at Garwood, N. J., as a designer of machinery.

In 1898 he had an attack of pleurisy, which greatly weakened him, and during the winter of 1898–9, he contracted a severe cough, which growing steadily worse developed into consumption, so that in the spring of 1899 he was compelled to give up work, to a considerable extent, and endeavor to recuperate. He went to Liberty, N. Y., where his health temporarily improved, but the loss of his little child caused a relapse and he went to Colorado. Finding the altitude too great, he returned to Liberty in September, where he died on October 30th, 1899.

Mr. Stratton was an able, faithful engineer, continuing his regular duties long after his physical condition demanded a rest. While enjoying the confidence of his employers, he was also beloved by all who were in any way associated with him, and his cheery presence will be missed by many.

American Institute of Electrical Engineers.

CATALOGUE OF MEMBERS.

May 1st, 1900.

HONORARY MEMBERS.

Name.	Address.	Date of Membership.
KELVIN, *Lord*, *D.C L.*, *LL.D.*, *F.R.S.*	Care of Library, The University, Glasgow, Scotland,	H.M. May 17, 1892
PREECE, *Sir.* WILLIAM. H., *K.C.B.*, *F.R.S.*	Consulting Electrical Engineer, London, Eng.; residence, Gothic Lodge, Wimbledon.	H.M. Oct. 21, 1884

Total, 2.

MEMBERS.

ABBOTT, ARTHUR V.	Chief Engineer, Chicago Telephone Co., 203 Washington St., Chicago, Ill.	A Oct. 21, 1890 M Jan. 16, 1895
ACHESON, EDW. G.	President, The Carborundum Co., Niagara Falls, N. Y.	A Jan. 3, 1888 M May 1, 1888
ADAMS, ALTON D.	Consulting Engineer, Box 1377, Boston, Mass.	A April 18, 1893 M Jan. 17, 1894
AHEARN, THOMAS	Ahearn & Soper, Electrical Supplies, Ottawa, Ont.	A July 12, 1887 M Sept. 6, 1887
ALBANESE, G. SACCO	Electrical Engineer, Tramways Electriques de Nice, Nice, France.	A Sept. 20, 1893 M Sept. 27, 1899
ALBRIGHT, H. FLEETWOOD	Electrical Engineer, Western Electric Co., New York; residence, 60 Sayre St., Elizabeth, N. J.	A Sept. 27, 1892 M June 20, 1894
ALDRICH, WILLIAM S.	Professor of Electrical Engineering, University of Illinois, Champaign, Ill.	A Mar. 15 1892 M April 25. 1900
ALMON, G. H.	Electrical Engineer and Contractor, Montpelier, Vt.	A Sept. 20, 1893 M Mar. 21, 1894
ANDREWS, WM. S	Manager Central Station Sales, General Electric Co., residence. 242 Union St, Schenectady, N. Y.	A Mar. 5, 1889 M April 22, 1896
ANSON, FRANKLIN ROBERT	Secretary and Manager, Salem Light and Traction Co., Salem, Ore.	A Feb. 27, 1895 M Nov. 23, 1898

Name.	Address	Date of Membership.
ANTHONY, PROF. W. A.	(*Past President.*) Consulting Electrician, Cooper Union; residence, 313 W. 33d St., New York, N. Y.	A Dec. 9, 1884 M Jan. 6, 1885
ARMSTRONG, CHAS. G.	Consulting Electrical Engineer, Fisher Building, Chicago, Ill.	A Sept. 27, 1892 M Aug. 31, 1898
ARNOLD, BION J.	Consulting Electrical Engineer, 1541 Marquette Bldg. and 4128 Prairie Ave., Chicago, Ill.	A Oct. 25, 1892 M Nov. 15, 1893
AYER, JAMES I.	General Manager American Electric Heating Corporation, Franklin and Sidney Sts., Cambridge, Mass.	A May 19, 1891 M April 19, 1892
AYRES, BROWN	Professor of Physics and Electrical Engineering, Tulane University, New Orleans, La.	A Dec. 16, 1891 M Mar. 15, 1892
BADT, LIEUT. FRANCIS B.	President, Badt-Goltz Engineering Co., 1504 Monadnock Block and 6506 Lafayette Ave., Chicago, Ill.	A April 19, 1892 M Mar. 25, 1896
BAILLARD, E. V.	Manufacturer of Electrical Instruments and Fine Machinery, Fox Building, New York City.	A Dec. 3, 1889 M Jan. 16, 1895
BALDWIN, BERT L.	Mechanical Engineer, The Cincinnati Street R'way Co., 73 Perin Bldg., Cincinnati, O.	A April 22, 1896 M Nov. 18, 1896
BARSTOW, WILLIAM S.	General Manager, Edison Electric Illuminating Co., 360 Pearl St., Brooklyn, N. Y.	A Feb. 21, 1894 M April 26, 1899
BATCHELOR, CHAS.	Electrical Engineer, 44 Broad St., New York City.	A June 8, 1887 M July 12, 1887
BATES, JAMES H. *M. E.*	New York office, F. L. Smidth & Co., No. 66 Maiden Lane, N. Y. City. Box 118 Hoboken, N.J.	A Sept. 6, 1887 M Oct. 1, 1889
BAYLIS, ROBERT NELSON	The Baylis Co., 99 Cedar St., New York City.	A Oct. 1, 1889 M May 17, 1892
BEDELL, DR. FREDERICK,	Assistant Professor in Physics, Cornell University, Ithaca, N. Y.	A April 21, 1891 M May 19, 1896
BELL, PROF. A. GRAHAM	(*Past President.*) 1331 Conn. Ave., Washington, D. C., and Baddeck, N. S.	A April 15, 1884 M Oct. 21, 1884
BELL, DR. LOUIS	Electrical Engineer, Boston, Mass.	A May 20, 1890 M June 18, 1890
BERNARD, EDGAR G.	Manufacturer, 450 Fulton St., Troy, N. Y.	A. Jan. 5, 1887 M July 12, 1886
BERTHOLD, VICTOR M.	Patent Department, American Bell Telephone Co., 125 Milk St., Boston; residence, 16 Upton St., Cambridgeport, Mass.	A May 17, 1892 M May 21, 1895
BETTS, PHILANDER 3d	Mech. & Electrical Engineer, Bureau of Yards and Docks, Navy Dept., residence, 653 I St., S. E., Washington, D. C.	A Mar. 25, 1896 M Jan. 25, 1899

Name.	Address.	Date of Membership.
BILLBERG, C. O. C.	Electrical Engineer, 3300 Arch St,. Philadelphia. Pa.	A Mar. 21, 1894 M Feb. 27, 1895
BIRDSALL, E. T. *M. E.*	Consulting Electrical Engineer, 26 Cortlandt St., residence, 56 West 38th St., New York City.	A June 8, 1887 M Nov. 1, 1887
BLADES, HARRY H.	Electrical Engineer, 419 Cass Ave., Detroit, Mich.	A April 19, 1892 M May 21, 1895
BLAKE, FRANCIS	Auburndale, Mass.	A Sept. 3, 1889 M Oct. 1, 1889
BLODGETT, GEO. W.	Electrical Engineer, B. & A. R. R. and Consulting Electrician, Boston, residence, Auburndale, Mass.	A July 12, 1887 M Sept. 6, 1887
BLOOD, JOHN BALCH	Blood and Hale, Consulting Engineers, Room 22–A, Equitable Building, Boston, Mass.	A June 20, 1894 M Dec. 18, 1895
BOGGS, LEMUEL STEARNS	With Sargent & Lundy, 1140 Monadnock Bldg., Chicago, Ill.	A Sept. 20, 1893 M May 17, 1898
BOILEAU, WILLARD E.	General Superintendent and Electrician, Brush Electric Light & Power Co., Consulting Engineer, Columbus R. R. Co., Columbus, Ga.	A Sept. 19, 1894 M Mar. 25, 1896
BOSCH, ADAM	Sup't Fire Alarm Telegraph, Newark, N. J.	A April 15, 1884 M Jan. 6, 1885
BOTTOMLEY, HARRY	Bellows Falls Electric Light Co., Bellows Falls, Vt.	A April 2, 1889 M Jan. 22, 1896
BOURNE, FRANK	Electrical Engineer, 26 Cortlandt St., New York City.	A April 21, 1891 M Nov. 15, 1892
BOYER, ELMER E.	Foreman, Testing Department, Lynn Works, General Electric Co., Lynn, Mass.	A Sept. 25, 1895 M Mar. 25, 1896
BOYNTON, EDWARD C.	Electrical Dep't, N. Y., N. H. & H. R. R., New Haven. Ct.	A Aug. 6, 1889 M Nov 24, 1891
BRADLEY, CHAS. S.	(*Manager.*) President, Ampere Electro Chemical Co , 44 Broad Street, residence, 42 W. 84th St , New York City.	A May 24, 1887 M Dec. 6, 1887
BRADY, FRANK W , *M. E.*	Professor of Engineering New Mexico College of Agriculture and Mechanic Arts, Mesilla N. M.	A June 20, 1894 M Mar. 28, 1900
BRENNER, WILLIAM H.	Constructing Engineer, Care of Frazar & Co., Yokohama, Japan.	A Sept. 20, 1893 M Mar. 21, 1894
BRINCKERHOFF, HENRY MORTON	Electrical Engineer, Metropolitan West Side Elevated R. R.; 258 Franklin St., Chicago, Ill.	A Sept. 23, 1896 M Dec. 16, 1896
BROOKS, MORGAN	Professor of Electrical Engineering, University of Nebraska; residence, 512 So. 16th St., Lincoln, Neb.	A May 20, 1890 M June 17, 1890
BROWN, ALFRED S.	Electrical Engineer, Western Union Telegraph Co., 195 Broadway, P. O. Box 856, New York City.	A Mar. 18, 1890 M Feb. 21, 1893

Name.	Address.	Date of Membership.
BROWN, J. STANFORD, *E.E.*, [Life Member.]	Consulting Electrical Engineer, Cor. Sec'y, Carpenter Steel Co., 1 Broadway; Vice-Pres't and Treas. Mutual Realty and Loan Corp; Treas., of the Realty-Loan Trust Co., 203 Broadway, New York City; residence, Park Hill, Yonkers, N.Y.	A Sept. 6, 1887 M Nov. 1, 1887
BROWNE, SIDNEY HAND.	Consulting Engineer, Duncan and Browne, 810 Equitable Bldg., residence, 14 E Eager St. Baltimore; P & A Tel. Bldg, Pittsburg, Pa.	A Apr. 28, 1897 M Nov. 23, 1898
BRUSH, CHAS. F.	Electrical Engineer, 453 The Arcade, Cleveland, O.	A April 15, 1884 M Oct. 21, 1884
BURCH, EDWARD P.	Consulting Electrical Engineer, 1210 Guaranty Loan Building, Minneapolis, Minn.	A Jan. 28, 1898 M May 17. 1898
BURLEIGH, CHAS. B.	Electrical Engineer, General Electric Co., 200 Summer St., Boston, residence, 1 Oak Terrace, Malden, Mass.	A April 21, 1891 M Feb. 16, 1892
BURTON, WILLIAM C.	Electrical Engineer, J. G. White Co. 29 Broadway, New York, N.Y.	A Sept. 20, 1893 M Dec. 27, 1899
CAHOON, JAS. BLAKE	Consulting Engineer, Onondaga County Savings Bank Building; residence, 729 Crouse Ave., Syracuse, N. Y.	A June 17, 1890 M May 19, 1891
CARHART, HENRY S.	Prof. of Physics, University of Michigan, Ann Arbor, Mich.	A Sept. 25, 1895 M April 22, 1896
CARROLL, LEIGH	President Algiers Waterworks and Electric Co., 708 Union St., New Orleans, La.	A Oct. 1, 1889 M Nov. 12, 1889
CARUS-WILSON, PROF. CHARLES A.	Consulting Engineer, 41 Old Queen St., Westminster, London, Eng.	A April 18, 1894 M April 17, 1895
CHAMBERLAIN, J. C.	Manager, The Electric Launch Co., Morris Heights; residence, 1 West 81st St., New York City.	A Dec. 6, 1887 M Jan. 3, 1888
CHANDLER, CHARLES F.	Professor of Chemistry, Columbia University, New York City.	A Jan. 20, 1891 M June 7, 1892
CHASE, HARVEY STUART	Mechanical and Electrical Engineer, 8 Congress St., Boston Mass.	A Sept. 19, 1894 M Jan. 22, 1896
CHENEY, W. C.	Electrical Engineer and Cont actor, Portland, Or.; residence, Oregon City, Or.	A Sept. 22, 1891 M Nov. 21, 1894
CHESNEY, CUMMINGS C.	Chief Electricial Engineer, Stanley Electric M'f'g. Co., Pittsfield, Mass.	A June 20, 1894 M Nov. 22, 1899
CHILDS, ARTHUR EDWARDS, *B. Sc. M.E., E.E.*	Vice-President and Treasurer, The Light, Heat and Power Corporation, 23 Central St., Boston, Mass.	A June 20, 1894 M April 17, 1895
CHUBBUCK, H. EUGENE	General Manager, Quincy Lighting Companies, Quincy, Ill.	A Dec. 4, 1888 M April 26, 1899
CHURCHILL, ARTHUR	British Thomson-Houston Co., 83 Cannon Street, London, E. C., Eng.	A April 15, 1890 M Jan. 17, 1893
CLARK, ERNEST P.	Electrical Engineer, B. Altman & Co, 19th St., and 6th Ave., New York City.	A Jan. 8, 1887 M Nov. 1, 1887

Name.	Address.	Date of Membership.
CLARKE, CHAS. L.	Electrical Engineer and Patent Expert, 31 Nassau St., New York City.	A April 15, 1884 M Jan. 6, 1885
COLBY, EDWARD A.	Consulting Engineer, Lock Box 113, Newark, N. J.	A April 2, 1889 M May 7, 1889
COLVIN, FRANK R.	Box 217, Roselle, N. J.	A April 18, 1894 M May 21, 1895
COMSTOCK, LOUIS K.	Electrical Engineer, Western Electric Co., Chicago, Ill.	A Dec. 20, 1893 M Nov. 20, 1895
CONDICT, G. HERBERT	Electrical Engineer, Columbia and Electric Vehicle Co., Hartford, Ct.	A July 12, 1887 M Sept. 6, 1887
CORNELL, CHARLES L.	Treasurer, Niles-Bement-Pond Co., 136 Liberty St., New York City.	A Feb. 7, 1890 M June 27, 1895
COSTER, MAURICE	45 Rue de la, Arcade, Paris, France.	A Sept. 25, 1895 M Mar. 25, 1896
COWLES, ALFRED H.	President the Cowles Electric Smelting and Aluminum Co., 361 The Arcade; residence, 656 Prospect St., Cleveland, O.	A Mar. 5, 1886 M May 7, 1889
CRAIG, J. HALLY	Representative, Crocker-Wheeler Co., 49 Federal St., Boston, Mass.	A May 16, 1893 M Feb. 27, 1895
CRANDALL, JOSEPH EDWIN	Electrician, C. & P. Telephone Co., 619 Fourteenth St., N. W. Washington, D. C.	A April 18, 1892 M April 18, 1894
CROCKER, FRANCIS BACON [Life Member.]	(*Past-President.*) Professor of Electrical Engineering, Columbia University; residence, 14 W. 45th Tel. 3823 38th New York.	A May 24, 1887 M April 2, 1889
CROSS, CHARLES R.	Thayer Professor of Physics, and Director of the Rogers Laboratory, Mass. Institute of Technology, Boston, Mass.	A April 15, 1884 M Oct. 21, 1884
CUSHING, HARRY COOKE, JR.	Electrical Consulting and Constructing Engineer, 39 Cortlandt St., New York City.	A Sept. 19, 1894 M Nov. 18, 1896
CUTTRISS, CHAS.	Electrician, The Commercial Cable Co., 20 Broad St., New York.	A Nov. 1, 1887 M Dec. 6, 1887
DAFT, LEO	Consulting Electrical Engineer 180 Noe St. San Francisco, Cal.	A Dec. 9, 1884 M Jan. 6, 1885
DARLINGTON, FREDERIC W.	Consulting Electrical and Mechanical Engineer, 931 Drexel Building, Philadelphia, Pa.	A Sept. 19, 1894 M Nov. 25, 1895
DAVIDSON, A.	Cable Engineer and Electrician, Central and South American Telegraph Co., Lima, Peru.	A May 18, 1897 M Oct. 27, 1897

Name.	Address.	Date of Membership.
DAVIS, CHARLES H., *C. E.*,	Engineering, 99 Cedar St., New York City, 204 Walnut Place, Philadelphia, Pa., 4 State Street, Boston, Mass; residence, Upper Montclair, N. J.	A Mar. 18, 1890 M June 17, 1890
DAVIS, MINOR M.	Traffic Manager, Postal Telegraph-Cable Co., 253 Broadway, New York City.	A April 6, 1886 M May 16, 1893
DAWSON, PHILIP	Associate and Chief Engineer with R. W. Blackwell, 39 Victoria St., Westminster, London, Eng.	A Sept. 25, 1895 M Feb. 17, 1897
DECKER, EDWARD P.	Engineer, with Westinghouse, Church, Kerr & Co., 26 Cortlandt St., New York City; residence, 496 Second St., Brooklyn, N. Y.	A Feb. 26, 1896 M Oct. 27, 1897
deKHOTINSKY, CAPT. ACHILLES,	Late Chief Electrician and Torpedo Officer, Imperial Russian Navy, 5526 Jefferson Avenue, Chicago, Ill.	A Oct. 27, 1891 M Nov. 22, 1899
DELAFIELD, A. FLOYD, *Ph. D.*	Electrical Engineer, Noroton, Conn.	A May 7, 1889 M Oct. 1, 1889
DELANY, PATRICK BERNARD	Inventor, South Orange N. J.	A April 19, 1884 M Nov. 24, 1891
DICKENSON, SAMUEL S.	Sup't, Commercial Cable Co., Hazel-Hill, Guysborough Co., N. S.	A Mar. 6, 1888 M Oct. 1, 1889
DIEHL, PHILIP	Inventor, Singer Sewing Machine Co., 508 Morris Ave., Elizabeth, N. J.	A April 15, 1884 M Dec. 9, 1884
DION, ALFRED A.	General Supt., The Ottawa Electric Co., Sparks St., Ottawa, Ont.	A Jan. 7, 1890 M Nov. 15, 1893
DOANE, SAMUEL EVERETT [Life Member.]	Sup't. Marlborough Electric Machine and Lamp Co., Marlborough, Mass.	A Aug. 6, 1889 M June 27, 1895
DODGE, OMENZO G., PROF.	U. S. Navy, Naval Academy, Annapolis, Md.	A Sept. 20, 1893 M April 17, 1895
DOIJER, H.	Consulting Electrical Engineer, 8 Choorstraat, Delft, Holland.	A Jan. 7, 1890 M Mar. 18, 1890
DOMMERQUE, FRANZ J.	Chief Engineer, Kellogg Switchboard and Supply Co., cor. Congress and Green Sts., Chicago, Ill.	A Oct. 17, 1894 M Mar. 25, 1896
DONNER, WILLIAM H.	McGraw Pub. Co, Dept. Machinery and Electricity, Exposition of 1900, Paris, France.	A Nov. 18, 1890 M Dec. 16, 1890
DOW, ALEX	Manager, Edison Illuminating Co., 18 Washington Ave.; residence, 844 Cass Ave., Detroit, Mich.	A Sept. 20, 1893 M Dec. 18, 1895
DUDLEY, CHARLES B	Chemist and Scientific Expert, Penn. R. R. Co., 1219 Twelfth Ave., Altoona, Pa.	A Oct. 1, 1889 M Nov. 12, 1889
DUNBAR, F. W.	234 La Salle St., Chicago; residence Highland Park, Ill.	A Dec. 21, 1892 M May 16, 1893
DUNCAN, DR. LOUIS	(*Past-President*) Duncan and Eyre, 71 Broadway, New York.	A July 12, 1887 M Sept. 6, 1887

Name.	Address.	Date of Membership.
DUNLAP, WILL KNOX	Supt. of Construction, Westinghouse Elec. and Mfg. Co., Pittsburg, Pa.	A Sept. 25, 1889 M June 24, 1895
DUNN, GANO SILLICK, *M.S.*,*E.E.* (*Manager.*)	Chief Engineer, Crocker-Wheeler Co., Ampere, N.J.; residence, 115 W. 71st St., New York City.	A April 21, 1891 M June 20, 1894
DUNSTON, ROBT. EDWARD	General Manager, Saratoga Traction Company, Saratoga Springs, N. Y.	A Oct. 27, 1891 M Feb. 16, 1892
DYER, R. N.	Patent Attorney, 31 Nassau St., New York City.	A July 12, 1887 M Sept. 6, 1887
EDISON, THOMAS A.	Mechanician and Inventor, Llewellyn Park, N. J.	A April 15, 1884 M Oct. 21, 1884
EDGAR, C. L.	President Edison Elec. Illuminating Co., of Boston, 3 Head Place, Boston; residence, 259 Kent St., Brookline, Mass.	A Jan. 22, 1896 M May 19, 1896
EGGER, ERNST	Technical Director, Vereinigte Elektricitäts Actien Gesellschaft, Simmeringstr, 187, Vienna, X., Austria.	A Feb 21, 1893 M Mar. 21, 1894
EMMET, W. L. R.	Electrical Engineer, General Electric Co., Schenectady, N. Y.	A June 6, 1893 M Jan. 17, 1894
FARNHAM, ISAIAH H.	Electrical Engineer, N. E. Telephone & Telegraph Co., 125 Milk St., Boston; residence, Wellesley, Mass.	A June 8, 1887 M July 12, 1887
FESSENDEN, REGINALD A.	Professor of Electrical Engineering, Western University of Pennsylvania, Allegheny, Pa.	A Oct. 21, 1890 M Dec. 16, 1890
FIELD, CORNELIUS J., *M. E.*	Consulting and Constructing Engineer, Vice-President, U. S. MotorVehicle Co ,1123 Broadway, New York City.	A June 8, 1887 M Nov. 1, 1887
FIELD, HENRY GEORGE	Consulting Engineer, Field & Hinchman, 1203 Majestic Building, Detroit. Mich.	A April 22, 1896 M Dec. 16, 1896
FIELD, STEPHEN D.	Electrical Engineer, Compagnie Genevoise de Tramways Electriques A "La Jonction," Geneva, Switzerland.	A April 15, 1884 M Oct. 21, 1884
FISCHER, GUSTAVE J.	Engineer for Tramway Construction, Public Works Department, Sydney, N. S. W.	A Jan. 20, 1891 M May 17, 1898
FISH, WALTER CLARK	Manager Lynn Works, General Electric Co., Lynn, Mass.	A June 26, 1891 M Feb. 26, 1896
FITZMAURICE, JAMES S.	Chief Engineer, The Electric Light Branch, 210 George St , Sydney, N S. W.	A Sept. 20, 1893 M Mar. 21, 1894
FLACK, J. DAY, *M. E.*	With Isbell Porter Co., 46 Bridge St., Newark; residence, 80 Carlton St., East Orange, N. J.	A Dec. 6, 1887 M May 21, 1895
FORTENBAUGH, S. B.	Cannon Street House, 110 Cannon Street, London, E. C., Eng.	A April 17, 1895 M Dec. 16 1896

Name.	Address.	Date of Membership.
FOSTER, HORATIO A.	Electrical Engineer, Room 682, Ellicott Square, Buffalo.	A June 8, 1887 M Sept. 6, 1887
FOSTER, SAMUEL L.	Chief Electrician, Market Street Railway Co., Market & Valentine Sts.; residence, 3687 24th St., San Francisco, Cal.	A Feb. 26, 1896 M Nov, 18, 1896
FREEDMAN, WILLIAM H.	Professor of Electrical Engineering University of Vermont; residence, 222 So. Union St., Burlington, Vt.	A Mar. 18, 1890 M Dec. 18, 1895
FREEMAN, DR. FRANK L.	Attorney-at-Law, Solicitor of Patents, Electrical Expert, 931 F St., Washington, D. C.	A May 7, 1889 M Sept. 3, 1889
GALE, HORACE B.	Mechanical and Electrical Engineer, Natick, Mass.	A Nov. 15, 1892 M May 16, 1893
GARDANIER, GEORGE W.	Asst. Electrical Engineer, Western Union Telegraph Co., 195 Broadway, New York City.	A April 18, 1893 M Jan. 22, 1896
GARRATT, ALLAN V.	Chief Engineer, Lombard Waterwheel Governor Co., 61 Hampshire St., Boston; residence, 603 Centre St., Jamaica Plain, Mass.	A April 2, 1889 M May 7, 1889
GERRY, M. H., JR.,	Engineer and Supt., Helena Water and Electric Power Company, Helena, Mont.	A April 18, 1893 M Oct. 21, 1896
GEYER, DR. WM. E.	Stevens Institute of Technology, Hoboken, N. J.	A June 5, 1888 M Sept. 7, 1888
GHARKY, WILLIAM DAVID	Electrical Engineer, Firm of Clement & Gharky, 1205–6 Stephen Girard Bldg., Philadelphia, and 56 McGill Bldg., Washington, D. C.	A May 21, 1895 M Feb. 26, 1896
GIBBS, LUCIUS T.	Asst. Engineer, U. S. Navy Dept., Washington, D. C.	A Mar. 25, 1896 M Feb. 17, 1897
GIFFORD, CLARENCE E.	Electrical Engineer, Walden Ave. Niagara Power Transformer Station, Buffalo Ry.; residence, 308 Prospect Ave., Buffalo, N. Y.	A May 16, 1893 M Feb. 21, 1894
GOLDSBOROUGH, WINDER	ELWELL, *M. E.*, Professor of Electrical Engineering and Director of Electrical Laboratory, Purdue University, 113 South St., Lafayette, Ind.	A Mar. 21, 1893 M Jan. 25, 1899
GOLTZ, WILLIAM	Badt-Goltz Engineering Co., 1504 Monadnock Block, Chicago, Ill.	A Oct. 27, 1897 M Feb. 23, 1898
GOSSLER, PHILIP GREEN	Electrical Engineer, Royal Electric Co., 94 Queen St., Montreal, P.Q.	A June 20, 1894 M June 24, 1898
GRAY, DR. ELISHA	Electrician and Inventor, 106 Sudbury St., Boston, Mass.	A Feb. 16, 1892 M May 17, 1892
GUTMANN, LUDWIG	Consulting Electrical Engineer, 111 Chambers Ave., Peoria, Ill.	A Sept. 14, 1888 M Mar. 21, 1893

Name.	Address.	Date of Membership.
HADAWAY, W. S., Jr.	Electric Heating Engineer, 107 Liberty St., New York City.	A Nov. 21, 1894 M Oct. 21, 1896
HALL, CLAYTON C.	Attorney-at-Law, and Consulting Actuary, Room 40, Maryland Life Building, 10 South St., Baltimore, Md.	A April 15, 1884 M Oct. 21, 1884
HALL, JOHN L.	Vallee Bros. Electric Company, 625 Arch St., Philadelphia, Pa.	A Sept. 22, 1891 M Dec. 20, 1893
HAMILTON, GEO. A.	(*Treasurer.*) Electrician, Western Electric Co., 57 Bethune St., New York; residence, 532 Morris Ave., Elizabeth, N. J.	A April 15, 1884 M Oct. 21, 1884
HAMMER, EDWIN W	Electrical Engineer, 46 Second Ave., Newark, N. J.	A Nov. 18, 1896 M June 23, 1897
HAMMER, WILLIAM J.	Consulting and Supervising Electrical Engineer, 922 Havemeyer Bldg, 26 Cortlandt St., residence, 153 W. 46th St., New York City.	A June 8, 1887 M July 12, 1887
HANCHETT, GEO. T.	Electrical and Technical Engineer, 123 Liberty St., N. Y.; residence, Hackensack, N. J.	A May 19, 1896 M Feb 15, 1899
HARRINGTON, WALTER E.	Electric Railway Engineer, 200 Market St., Camden, N. J.	A Mar. 17, 1891 M May 19, 1896
HARRISON, RUSSELL B.	Pres. and Electrical Engineer, Terre Haute Electric Railway Co., Terre Haute, Ind.	A Sept. 25, 1895 M April 22, 1896
HARTWELL, ARTHUR	Manager Chicago office, Westinghouse Electric and Mfg Co.; 171 La Salle Street, Chicago, Ill	A May 15, 1894 M Nov. 20, 1895
HASKINS, CARYL D.	Electrical Engineer, General Electric Co., 180 Summer St., Boston, Mass.	A Mar, 18, 1890 M June 20, 1894
HASKINS, CHARLES H.	Electrician, 70 Linwood Avenue, Buffalo, N. Y.	A April 15, 1884 M Oct. 21, 1884
HASKINS, CLARK CARYL	Electrical Engineer, 682a West Adams St., Chicago, Ill.	A Sept. 20, 1893 M Mar. 21, 1894
HASSON, W. F. C.	Consulting Engineer, Judd Building Honolulu, H.I.	A Mar. 18, 1890 M May 15, 1894
HAYES, HAMMOND V.	Electrical Engineer, the American Bell Telephone Co., 125 Milk St., So. Boston; residence, Cambridge, Mass.	A Nov. 12, 1889 M Mar. 18, 1890
HAYES, HARRY E.	Asst. Electrician, American Telegraph and Telephone Co., 22 Thames St., New York City.	A April 18, 1893 M Dec. 20, 1893
HAYNES, F. T. J.	Divisional Telegraph Engineer, Great Western Railway; residence, Belmont Villa, Cheddon Road, Taunton, Eng.	A Dec. 6, 1886 M Jan. 3, 1887
HEATH, HARRY E.	Chief Engineer, Eddy Electric M'f'g. Co., Windsor, Conn.	A Mar. 21, 1893 M Mar. 25, 1896
HEINRICH, RICHARD O.	General Manager, European Weston Electrical Instrument Co., 88 Ritterstrasse, Berlin, Germany.	A Oct. 1, 1889 M Oct. 25, 1892

Name.	Address.	Date of Membership.
HENSHAW, FREDERICK V.	Erecting Engineer, Crocker-Wheeler Co., Ampere, N. J.. residence, 148 Henry St., Brooklyn, N. Y.	A Feb. 5, 1889 M Nov. 20, 1895
HERDMAN, FRANK E.	Mechanical and Electrical Engineer, Crane Elevator Co., Winnetka, Ill.	A Dec. 18, 1895 M Oct. 21, 1896
HERING, CARL [Life Member.]	Consulting Electrical Engineer, 929 Chestnut St.; Philadelphia, residence, Lehman Lane, Germantown, Pa.	A Jan. 3, 1888 M June 5, 1888
HERRICK, CHARLES H.	Superintendent Isolated, Lighting and Power Dep't., Edison Electric Illuminating Co., 3 Head Place, Boston; residence, 22 Herrick St., Winchester, Mass.	A April 21, 1891 M Jan. 17, 1893
HERZOG, F. BENEDICT, *Ph. D.*	President, Herzog Teleseme Co., 51 W. 24th St., New York City.	A May 24, 1887 M July 12 1887
HEWITT, CHARLES	Electrical Engineer, Union Traction Co., 809 Spruce Street, Philadelphia, Pa.	A Sept. 16, 1890 M May 17, 1892
HEWLETT, ERNEST HOLCOMBE	Electrical Engineer in Chief Control Rockhampton Gas & Coke Co., Ltd.; residence Estoril, Rockhampton, Queensland, Australia.	A Aug. 23, 1899 M. Dec. 27, 1899
HIBBARD, ANGUS S.	General Manager Chicago Telephone Co., 203 Washington St., Chicago, Ill.	A Nov. 24. 1891 M Feb. 16, 1892
HIGGINS, EDWARD E.	Editor, *Street Railway Journal*, 120 Liberty St ; residence. 28 W. 120th St., New York City.	A June 8, 1887 M July 12, 1887
HOBART, HENRY M.	Engineer, care British Thomson-Houston Co., 83 Cannon St., London, Eng.	A April 18, 1894 M Sept. 27, 1899
HOLMES, FRANKLIN S.	Electrical Engineer, 108 Fulton St , New York City ; residence 348 E. 12th St., Brooklyn, N. Y.	A April 21, 1891 M June 20, 1894
HOUSTON, EDWIN J., *Ph.D.* (*Past President.*) [Life Member.]	Prof of Physics, Franklin Inst., Firm of Houston & Kennelly, Crozer Bldg., 1420 Chestnut St. : residence, 1809 Spring Garden St., Phila., Pa.	A April 15, 1884 M Oct. 21, 1884
HOWELL, JOHN W.	Engineer, Lamp Works General Electric Co Harrison; residence, Ballantine Parkway, Newark, N.J.	A July 12, 1887 M June 5, 1888
HOWELL, WILSON S.	Test Officer, Lamp Testing Bureau, 5th and Sussex Sts , Harrison; residence, Ward Place, South Orange, N. J.	A Sept. 3, 1889 M Mar. 18, 1890
HUMPHREY, HENRY H.	Consulting Electrical Engineer, Bryan & Humphrey, 708 Lincoln Trust B'ld'g., St Louis, Mo.	A Dec. 16, 1896 M April 28, 1897

Name.	Address.	Date of Membership.
HUNTER, RUDOLPH M.	Expert and Counsellor in Patent Causes, 926 Walnut St., Philadelphia, Pa.	A July 13, 1886 M May 17, 1887
HUNTING, FRED S.	Chief Engineer, Engineering Department, Fort Wayne Electric Co., 325 West Washington St., Fort Wayne, Ind.	A Nov. 15, 1892 M May 16, 1893
HUTCHINSON, DR. CARY TALCOTT [Life Member.]	(*Vice-President.*) Consulting Electrical Engineer, 71 Broadway, New York City.	A Feb. 7, 1890 M Dec. 16, 1890
HYDE, JEROME W.	Ass't Treasurer, The Springfield Steam Power Co., Wason Bldg. Springfield, Mass.	A June 8, 1887 M Nov. 1, 1887
INRIG, ALEC GAVAN	Globe Electrical Co., Arthur Villa, Agnes Road Blundellsands, near Liverpool, Eng.	A Jan. 19, 1892 M May 17, 1892
IVES, EDWARD B.	Signal Officer, U. S. Volunteers, War Dept., Washington, D. C.	A April 2, 1889 M May 15, 1894
JACKSON, DUGALD C.	Consulting Engineer, Professor of Electrical Engineering, University of Wisconsin, Madison, Wis.	A May 3, 1887 M June 17, 1890
JACKSON, FRANCIS E.	Incandescent Filaments Manufacturer. 128 Essex Ave, Orange; residence, 61 South Grove St., East Orange, N. J.	A Jan. 3, 1888 M June 17, 1890
JACKSON, HENRY	Telegraph Supt. and Engineer, The Lancashire & Yorkshire Railway Co., Horwich, Bolton-le Moors, Lancashire, England.	A Mar. 21, 1894 M Dec. 19, 1894
JACKSON, JOHN PRICE	Professor of Electrical Engineering, Penn. State College, State College, Pa.	A Sept. 27, 1892 M Jan. 17, 1894
JACKSON, WM. B.	Supt., The Colorado Electric Power Co., Box 792, Victor, Col.	A Aug. 13, 1897 M June 24, 1898
JANNUS, FRANKLAND	Attorney-at-Law, Solicitor of Patents, 140 Broadway, (Tel. 3565 Cortlandt), New York City.	A Nov. 12, 1889 M Mar. 18, 1890
JEHL, FRANCIS	VII Kazinczy-utczo 21, Budapest, Hungary.	A June 27, 1895 M Jan. 22, 1896
JENKS, W. J.	Secretary, Board of Patent Control, 120 Broadway, New York City; residence, 497 4th St., Brooklyn, N. Y.	A June 8, 1887 M Nov. 1, 1887
JOHNSTON, A. LANGSTAFF	Chief Engineer, Richmond Traction Co., 1112 E. Main St., Richmond, Va.	A April 21, 1891 M April 18, 1894
JONES, FRANCIS WILEY [Life Member.]	Assistant Gen'l-Manager and Electrician, Postal Telegraph-Cable Co., 253 Broadway, New York City	A April 15, 1884 M Oct. 21, 1884
KEITH, DR. NATHANIEL S.	Electro-Metallurgist, 62 Nevada Block, San Francisco, Cal.	A April 15, 1884 M Jan. 17, 1894

Name.	Address.	Date of Membership.
KENNELLY, ARTHUR E. [Life Member.]	(*President*) Electricial Engineer, Firm of Houston & Kennelly, 1203–4 Crozer Bldg., 1420 Chestnut St.; residence, The Landsowne, N. 41st St. and Parkside Ave , Philadelphia, Pa.	A May 1, 1888 M May 16, 1899
KINSMAN, FRANK E.	Electrical Engineer, 26 Cortlandt St., New York City; residence, 836 Sherman Ave., Tel. 1024, Plainfield, N. J.	A Sept 27, 1892 M May 16, 1893
KNOWLES, EDWARD R.	*E. E., C. E.* Consulting Electrical Engineer, 136 Liberty St., New York City: residence, 82 Cambridge Place, Brooklyn. N. Y.	A June 8, 1887 M July 12, 1887
KNOX, CHAS. EDWIN	With C. O. Mailloux, Consulting Electrical Engineer, 150 Nassau St.; residence, 108 W. 122nd St., New York, N. Y.	A. May 16, 1899 M. Dec. 27, 1899
KNUDSON, A. A.	Electrical Engineer, Room 416, 32 Nassau St., New York City, Telephone 617 Cortlandt;residence,127 Prospect Place, Rutherford, N. J.	A Dec. 6, 1887 M Jan. 3, 1888
LANGE, PHILIP A.	Superintendent Westinghouse Electric and Manufacturing Co., East Pittsburg, Pa.	A Mar. 6, 1888 M June 5, 1888
LANGTON, JOHN	Electrical Engineer, Canada Life Building, Toronto, Ont., and 72 Trinity Place, New York, N. Y.	A Mar. 6, 1888 M June 5, 1888
LARDNER, HENRY ACKLEY	J. G. White & Co., 29 Broadway, New York City; residence, 93 Clark St., Brooklyn, N. Y.	A Dec. 19, 1894 M May 16, 1899
LA ROCHE, FRED. A.	Senior Member of F. A. La Roche & Co., 652–660 Hudson Street; residence, 28 W. 25th St., New York.	A Sept. 19, 1894 M Nov. 20, 1895
LATTIG, J. W.	Electrical Engineer, residence, 335 West Broad St., Bethlehem, Pa	A June 8, 1887 M July 12, 1887
LEMP, HERMANN, JR.	Electrician, 186 Allen Avenue, Lynn, Mass.	A April 2, 1889 M Feb. 21, 1893
LEONARD, H. WARD [Life Member.]	Electrical Engineer, Pres't. Ward Leonard Electric Co , Bronxville, N Y.; residence, Lawrence Park, N. Y.	A July 12, 1887 M Sept. 6, 1887
LESLIE, EDWARD ANDREW	Vice-President and Manager, Manhattan Electric Light Co., Ltd., 57 Duane Street, New York City; residence, 262 Hancock Street, Brooklyn, N. Y.	A Jan. 16, 1895 M Feb. 17, 1897
LEVIS, MINFORD	Superintendent and Electrical Engineer, Novelty Electric Co., 54 North 4th St., Philadelphia, Pa.	A Feb. 21, 1893 M June 23, 1897
LIEB, JOHN WILLIAM, JR.	(*Vice-President*) General Mgr., Edison Electric Ill. Co.; Residence, 166 West 97th St., New York City.	A Sept. 6, 1887 M Nov. 1, 1887
LIGHTHIPE, JAMES A.	District Engineer, General Electric Co., Claus Spreckels Bldg., San Francisco, Cal.	A Feb. 21, 1894 M April 17, 1895
LINCOLN, PAUL M.	Electrical Supt. Niagara Falls Power Co., Niagara Falls, N. Y.	A Sept. 25, 1895 M June 24, 1898

Name.	Address.	Date of Membership.
LLOYD, HERBERT	(*Manager*) Vice President and General Manager, Electrical Engineer and Chemist, The Electric Storage Battery Co., Drexel Bldg., Philadelphia, Pa.	A June 20, 1894 M May 21, 1895
LLOYD, JOHN E.	Chief Engineer and General Manager Cape Town Tramways, 49 Sir Lowry Road, Cape Town, S. Africa.	A Jan. 22, 1896 M Mar. 25, 1896
LLOYD, ROBERT MCA.	Electrician, 100 Broadway; residence, 9 East 9th St., New York City.	A Oct. 21, 1890 M Nov. 15, 1893
LOCKWOOD, THOMAS D., [Life Member.]	Electrical Engineer, and Advisory Electrician, P. O. Drawer 2, Boston, Mass.	A April 15, 1884 M Oct. 21, 1884
LOOMIS, OSBORN P.	Electrical Engineer, Newport News Shipbuilding and Dry Dock Co., Newport News, Va.	A Sept. 16, 1890 M Dec. 16, 1896
LORRAIN, JAMES GRIEVE	Norfolk House, Norfolk St., London, W. C., England.	A May 16, 1891 M May 15, 1894
LOVEJOY, J. R.	General Manager, Supply Dept., General Electric Co., Schenectady, N. Y.	A April 21, 1891 M Feb. 21, 1894
LOZIER, ROBERT T. E.	Manager, Bullock Electric Co., St. Paul Bldg., New York City; residence, 326 Richmond Terrace, New Brighton, S. I.	A May 20, 1890 M Jan. 24, 1900
MACCOUN, ANDREW ELLICOTT	Supt. of the Electrical Dep't., The Carnegie Steel Co., Braddock, Pa.	A Nov. 20, 1895 M July 18, 1899
MACFARLANE, ALEXANDER, *D. Sc., LL.D.*	(*Manager.*) Lecturer on Mathematical Physics Lehigh University, South Bethlehem, Pa.	A Jan. 19, 1892 M May 17, 1892
MAILLOUX, C. O. [Life Member.]	(*Manager*) Consulting Electrical Engineer, 150 Nassau St., Telephone 3985 Cortlandt; residence, 48 W. 73d St. NewYork.	A April 15, 1884 M Oct. 21, 1884
MANSFIELD, ARTHUR NEWHALL	Assistant Electrician, American Telephone and Telegraph Co., 22 Thames St., New York City.	A Dec. 20, 1893 M June 20, 1894
MARKS, LOUIS B., *M. M. E.*	President, Marks Enclosed Arc Light Co., 689 Broadway; residence, 51 East 67th St., New York City.	A May 20, 1890 M Jan. 16, 1895
MARKS, WILLIAM DENNIS, *Ph.B. C. E.*	President, The American Electric Meter Co., 9th and Montgomery Ave.; President, General Electric Automobile Co., Bourse Bldg., Philadelphia, Pa.	A Feb. 7, 1888 M May 1, 1888
MARSHALL, J. T.	Metuchen, N. J.	A Oct. 1, 1889 M Nov. 12, 1889
MARTIN, JULIUS	Master Electrician, Navy Yard, Brooklyn; residence, 103 E. 10th St., New York City.	A Oct. 21, 1890 M Nov. 20, 1895
MARVIN, HARRY N.	c/o American Mutoscope and Biograph Co., 841 Broadway, New York City.	A April 19, 1892 M Jan. 17, 1893

Name.	Address.	Date of Membership.
MAVER, WILLIAM, JR.	Electrical Expert and Consulting Electrical Eng'r, 120 Liberty St., New York City; residence, 227 Arlington Ave. (Tel. 1282 Bergen) Jersey City, N. J.	A July 12, 1887 M April 21, 1891
MAYER, GEORGE M.	Electrical and Mechanical Engineer, 1401 Monadnock Bldg., Chicago, Ill.	A Dec. 16, 1890 M June 20, 1894
MAYNARD, GEO. C.	Electrical Engineer, Smithsonian Institution, Washington, D. C.	A April 15, 1884 M Dec. 9, 1888
McCAY, H. KENT	Electrical Engineer and Contractor, 106 E. German St., Baltimore, Md.	A Sept. 16, 1890 M May 19, 1891
McCROSKY, JAMES W.	Chief Engineer, La Capital Tramway Co. and Compañia de Luz y Fuerza Motriz de Cordoba, Reconquista 20, Buenos Aires, Argentina.	A Dec. 20, 1893 M Dec. 16, 1896
McCROSSAN, J. A.	Manager and Electrician, Citizens' Telephone and Electric Co., Rat Portage, Ont.	A Oct. 18, 1893 M Dec. 18, 1895
McMEEN, SAMUEL G.	Engineer, Central Union Telephone Co., 1306 Ashland Block, Chicago. Ill.,	A Dec. 18, 1895 M Dec. 16, 1896
MERSHON, RALPH D.	Electrical Engineer, with Westinghouse Electric and Mfg. Co., 120 Broadway, N. Y. City.	A Mar. 20, 1895 M Jan. 22, 1896
MILLIS, JOHN	Major of Engineers U. S A., Army Bldg, 29 Whitehall St., New York.	A July 7, 1884 M Mar. 3, 1885
MITCHELL, JAMES [Life Member.]	Constructing Engineer and Agent, General Electric Co., Caixa do Correio No. 954, Rio de Janeiro, Brazil.	A Sept. 25, 1895 M Mar. 25, 1896
MIX, EDGAR W.	Electrical Engineer, 12 Boulevard des Invalides, Paris, France.	A Sept. 3, 1889 M Mar. 20, 1895
MOLERA, E. J.	Civil and Electrical Engineer, 606 Clay St., San Francisco, Cal.	A Jan. 16, 1892 M June 7, 1892
MOORE, D. McFARLAN	Inventor, Moore Electrical Co., 52 Lawrence St., Newark, N. J.	A Dec. 20, 1893 M June 20, 1894
MOORE, WM. E.	General Superintendent and Electrician, The Augusta Railway & Electric Co., Augusta, Ga.	A Jan. 22, 1896 M Sept. 27, 1899
MORROW, JOHN THOMAS	Supt. Electrolytic Plant, Boston and Montana Consolidated Copper and Silver Mining Co., Great Falls, Mont.	A Dec. 21, 1892 M April 18, 1894
NEILER, SAMUEL G.	Member of the Firm of Pierce, Richardson & Neiler, Consulting and Designing Engineers, 1405–12 Manhattan Building; residence, Hotel Del Prado, Chicago, Ill.	A April 18, 1894 M Dec. 18, 1895
NICHOLS, DR. EDWARD L.	Professor of Physics, Cornell University, Ithaca, N. Y.	A Oct. 4, 1887 M Dec. 6, 1887
NICHOLS, GEO. P.	Partner, Geo. P. Nichols & Bro., Elec. Engineers and Contractors, 1036 Monadnock Bldg., Chicago, Ill.	A Jan. 22, 1896 M Nov. 18, 1896

Name.	Address.	Date of Membership.
NICHOLSON, WALTER W.	General Supt. Central N. Y. Telephone and Telegraph Co., Telephone Building, Syracuse, N. Y.	A May 15, 1894 M May 18, 1897
NOLL, AUGUSTUS	Contracting Electrical Engineer, 8 East 17th St., Telephone, 62, 18th; New York City.	A Sept. 27, 1892 M April 18, 1893
NUNN, PAUL N.	Chief Engineer, Telluride Power Co., Telluride, Colo.	A April 17, 1895 M Feb. 26, 1895
O'CONNELL, JOSEPH J.	Telephone Engineer, Chicago Telephone Co., Residence, 76 Eugene St., Chicago, Ill.	A Oct. 17, 1894 M Nov. 20, 1895
O'DEA, MICHAEL TORPEY	Professor of Applied Electricity, University of Notre Dame, 73 No. State St., Chicago, Ill.	A June 8, 1887 M Mar 25, 1896
OUDIN, MAURICE A.	Electrical Engineer, General Electric Co., Schenectady, N. Y.	A June 20, 1894 M Nov. 20, 1895
OWENS, ROBERT BOWIE	(*Vice-President.*) McDonald Professor of Electrical Engineering, McGill University, Montreal, P.Q.	A June 17, 1890 M Dec. 15, 1897
PAINE, F. B. H.	Westinghouse Electric and Mfg. Co., 120 Broadway, New York, N. Y.	A Dec. 16, 1890 M Nov. 25, 1891
PAINE, SIDNEY B.	General Electric Co., 180 Summer St., Boston, Mass.	A June 8, 1887 M Nov. 1, 1887
PARKER, LEE HAMILTON	The Buenos Aires and Belgrano Electric Tramways Co., Calle Santa Fé No, 2457, Buenos Aires.	A Aug. 5, 1895 M Dec. 16, 1896
PARKS, C. WELLMAN	Civil Engineer, U. S. N., U. S. Naval Station, San Juan, P. R.	A July 12, 1887 M May 1, 1888
PARSHALL, HORACE FIELD	Consulting Engineer, 8 Princes St. Bank, E. C., London, Eng.	A Sept. 7, 1888 M Mar. 18, 1890
PATTISON, FRANK A.	Firm of Pattison Bros, Consulting and Constructing Electrical Engineers, 141 Broadway, New York City.	A Sept. 22, 1891 M Dec. 16, 1891
PEARSON, F. S.	Engineer, Room 841, 621 Broadway, New York City.	A Oct. 25, 1892 M Feb. 21, 1893
PEDERSEN, FREDERICK MALLING	Instructor in Physics, College of the City of New York, 17 Lexington Ave.; residence, 39 Washington Square, New York City.	A Sept. 20, 1893 M June 24, 1898
PEROT, L. KNOWLES	President of The Schuylkill Valley Illuminating Co., Phœnixville, Pa.	A Mar. 15, 1892 M Dec. 18, 1895
PERRINE, FREDERIC A. C., *D. Sc.*	(*Manager.*) President Stanley Electric M'f'g Co., Pittsfield, Mass.	A Sept. 16, 1890 M Dec. 16, 1890
PICKERNELL, F. A.	Chief Engineer, Amer. Tel. & Tel. Co., 22 Thames St., New York City.	A Feb. 7, 1890 M Mar. 18, 1890

Name.	Address.	Date of Membership.
PIERCE, RICHARD H.	Pierce, Richardson & Neiler, Electrical Engineers, 1409 and 1410 Manhattan Bldg., Chicago; residence, 5434 Monroe Ave., Hyde Park, Ill.	A April 18, 1893 M Dec. 20, 1893
PIKE, CLAYTON W., *B.S.*	Electrical Engineer, Falkenau Engineering Co., 711 Reading Terminal, Philadelphia, Pa.	A Dec. 16, 1891 M Oct. 25, 1892
PORTER, JOSEPH F	(*C. E.*) President and Managing Engineer. Alton Railway, Gas and Electric Co., Alton, Ill.	A Sept. 6, 1887 M Nov. 1, 1887
POTTER, WM. BANCROFT,	Engineer Railway Dept., General Electric Co., Schenectady, N. Y.	A Jan. 22, 1896 M Mar. 25, 1896
PRATT, ROBERT J.	Electrician, Honolulu Iron Works, Honolulu, H. I.	A July 12, 1887 M Sept. 6, 1887
PUFFER, WM. L.	Assistant Professor of Electrical Engineering, Mass. Institute of Technology, Boston; residence, West Newton, Mass.	A Dec. 20, 1893 M April 17, 1895
RAE, FRANK B.	Rae and Monroe, Electrical and Mechanical Engineers, 804 Fort Dearborn Bldg., 134 Monroe St., Chicago, Ill.	A April 15, 1884 M Oct. 25, 1892
REBER, SAMUEL	Lieut. Col. Signal Corps, U. S., Governor's Island, New York City.	A Sept. 20, 1893 M Jan. 22, 1896
RECKENZAUN, FREDERICK,	Electrical Engineer, 44 Pine St., New York City.	A Mar. 6, 1888 M June 5, 1888
REDMAN, GEO. A.	General Supt., Electric Dept., Brush Elec. Light Co., and Rochester Gas and Elec. Co., 66 Andrews St.; residence, 30 Park Ave., Rochester, N. Y	A Feb. 27, 1895 M May 17, 1898
REID, THORBURN	Consulting Electrical Engineer, 120 Liberty St., New York City.	A Oct. 21, 1890 M June 24, 1898
REIST, HENRY G.	Designing Engineer, General Electric Co., 5 South Church St., Schenectady, N. Y.	A June 17, 1890 M Dec, 19, 1894
RENO, C. STOWE	Electrical Engineer, Triumph Electric Co., 620 Baymiller Street, Cincinnati, Ohio.	A Nov. 23, 1898 M July 18, 1899
RICE, CALVIN WINSOR	Electrical Engineer, Edison Electric Illuminating Co. of New York. Electrician, Consolidated Telegraph and Electrical Subway Co., 57 Duane St., New York City.	A Jan. 20, 1897 M April 28, 1897
RICE, E. WILBUR, JR.	Technical Director, The General Electric Co., Schenectady, N. Y.	A Dec. 6, 1887 M Jan. 3, 1888
RICHARDSON, ROBERT E.	Vice-President of Pierce, Richardson & Neiler, 1409 Manhattan Building residence, 88 E. 34th St., Chicago, Ill.	A Sept. 19, 1894 M May 18, 1897
RIDLEY, A. E. BROOKE	Electrical Engineer and Contractor, Parrot B'ldg. San Francisco, Cal.	A Nov. 21, 1894 M Nov. 23, 1898
RIES, ELIAS E.	Electrical Engineer and Inventor, 1242 New York Life Insurance Bldg.; residence, 4 W. 115th St., New York City.	A July 12, 1887 M Sept. 6, 1887

Name.	Address.	Date of Membership.
RIKER, ANDREW L. [Life Member.]	Electrical Engineer, The Riker Electric Vehicle Co , Elizabethport, N. J.	A Nov. 1, 1887 M Dec. 18, 1895
ROBB, RUSSELL	With Stone & Webster, 4 P. O. Square, Boston, Mass.	A Oct. 18, 1893 M May 21, 1895
ROBB, WM. LISPENARD	Professor of Physics, Trinity College, and 118 Vernon St., Hartford, Conn.	A Dec. 16, 1891 M Mar. 15, 1892
ROBERTS, E. P.	E. P. Roberts & Co., Consulting Engineers, Electric Building, Telephone 2656; residence, 95 Cornell St., Cleveland, O.	A Jan. 6, 1885 M Feb. 3, 1885
RODGERS, HOWARD S.	Electrical Engineer, care General Electric Co., 420 W. 4th Street, Cincinnati, O.; residence, 190 E. 2d St., Covington, Ky.	A Sept. 27, 1892 M May 16, 1893
ROHRER, ALBERT L.	Electrical Supt. Schenectady Works General Electric Co.; residence, 20 Union St., Schenectady, N. Y.	A Nov. 1, 1887 M May 1, 1888
ROLLER, JOHN E.	Lieut. Commander U. S. N., Navy Department, Washington, D. C.	A Sept. 19, 1894 M May 19, 1896
ROSA. EDWARD B.	Professor of Physics, Wesleyan University, Middletown, Conn.	A Feb. 17, 1897 M May 18, 1897
ROSS, NORMAN N.	Electrical Engineer, The Royal Electric Co., Montreal, Can.	A Sept. 20, 1893 M Nov. 21, 1894
ROSS, ROBERT A.	Mechanical and Electrical Consulting Engineer, 17 St. John St., Montreal, P. Q.	A Sept. 27, 1892 M April 18, 1893
ROUQUETTE, WILLIAM F. B. [Life Member.]	Proprietor, Rouquette & Co., 47 Dey St., New York City.	A Mar. 21, 1894 M Dec. 19, 1894
RYAN, HARRIS, J.	Professor of Electrical Engineering, Cornell University; residence, Cascadilla Place, Ithaca, N. Y.	A Oct. 4, 1887 M April 17, 1895
SACHS, JOSEPH	Electrical Engineer, The Johns-Pratt Company; residence, 220 Collins St., Hartford Conn.	A Mar. 15, 1892 M Dec. 15, 1897
SALOMONS, *Sir* DAVID LIONEL, *Bart. M. A.*, [Life Member]	Engineer and Barrister, Broomhill, Tunbridge Wells, Kent, and 49 Grosvenor St., London, W. England.	A Feb. 7, 1888 M May 1, 1888
SAMPSON, F. D.	Manager, Charlotte Electric Light and Power Co., Charlotte, N. C.	A Aug. 5, 1896 M Oct. 27, 1897
SANDS. H. S.	Consulting and Constructing Electrical Engineer, 1153 Market St., Wheeling, W. Va.	A Feb. 21, 1893 M Nov. 21. 1894
SARGENT, WILLIAM D.	Vice Prest. and General Manager, N. Y. & N. J. Tel. Co., 81 Willoughby St.; residence, 820 Union St., Brooklyn, N. Y.	A April 15, 1884 M Feb. 21, 1894
SCHEFFLER, FRED. A.	Manager, Water Tube Boiler Dept., James Beggs & Co , 9 Dey St., N. Y. City; residence, 33 Snowden Pl., Glen Ridge, N. J.	A May 16, 1893 M Jan. 26, 1896
SCHMID, ALBERT	Directen Genèral de la Sociètè Industrielle d'Electricitè procèdès Westinghouse, 45 rue de l'Arcade Paris, France.	A Oct. 21, 1890 M April 17, 1895

Name.	Address.	Date of Membership.
SCHOEN, A. M.	Electrician, South Eastern Tariff Association, 339 Equitable Building, Atlanta, Ga.	A Sept. 20, 1893 M Dec. 16, 1896
SCOTT, CHARLES F.	Chief Electrician, Westinghouse Electric and Mfg. Co., Pittsburg, Pa.	A April 19, 1892 M Jan. 17, 1893
SCOTT, JAMES B.	Consulting Electrical, and Mechanical Engineer. 227 East German St.; residence, 847 Ducatel St., Baltimore Md.	A Aug. 5, 1896 M May 17, 1898
SEVER, GEORGE F.	(*Manager.*) Instructor in Electrical Engineering, Columbia University, New York City.	A Jan 17, 1894 M May 19, 1896
SHAW, EDWIN C.	Mechanical Engineer, The B. F. Goodrich Co., Akron, O.	A May 17, 1892 M Feb. 27, 1895
SHEA, DANIEL W.	Professor of Physics, Catholic University of America, Washington, D. C.	A Dec. 20, 1893 M June 20, 1894
SHELDON, SAMUEL, *A. M.*, *Ph.D.*	(*Manager.*) Professor of Physics and Electrical Engineering, Polytechnic Institute, 198½ Schermerhorn St., Brooklyn, N.Y.	A Dec. 16, 1890 M Oct. 27, 1891
SHEPARDSON, GEORGE D.	Professor of Electrical Engineering, University of Minnesota, Minneapolis, Minn.	A April 21, 1891 M Jan. 22, 1896
SINCLAIR, H. A.	Electrical Engineer, The Tucker Electric Co., 35 South William St., New York; 950 Bedford Ave. Brooklyn, N. Y.	A June 17, 1890 M Feb. 26, 1896
SMITH, FRANK E.	Consulting and Supervising Electrical Engineer, 183 Jessie St.; residence, 418 Eugenia Ave., San Francisco, Cal.	A Sept 19, 1894 M July 18, 1899
SMITH, FRANK STUART	Supt. Lamp Factory, Sawyer-Man Electric Co., Pittsburg, Pa.	A Sept. 27, 1892 M April 18, 1893
SMITH, HAROLD BABBITT	Professor of Electrical Engineering, Worcester Polytechnic Institute; residence, 20 Trowbridge Road, Worcester, Mass.	A Nov. 24, 1891 M April 25, 1900
SMITH, JESSE M.	Expert in Patent Causes, Consulting Electrical and Mechanical Engineer, 36 Moffat Block, Detroit, Mich., and 218 Broadway, New York City.	A April 15, 1884 M June 26, 1891
SMITH, T. CARPENTER	Member of Firm of M. R. Muckle, Jr., & Co., 650 Drexel Bldg.; residence, The "Newport," Philadelphia, Pa.	A Oct. 27, 1891 M Dec. 16, 1891
SPAULDING, HOLLON C.	Contracting Engineer, American Stoker Co., 410 Exchange B'ld'g, Boston; residence, 15 Park Vale, Brookline, Mass.	A April 21, 1891 M June 20, 1894
SPERRY, ELMER A.	Electrical Engineer, 855 Case Ave., Cleveland, O.	A April 19, 1892 M Feb. 21, 1893
SPRAGUE, FRANK J.	(*Past-President.*) Consulting Engineer, Sprague Electric Co., New York City	A May 24, 1887 M Feb. 17, 1897
STANLEY, WILLIAM	(*Vice-President.*) Electrical Engineer and Inventor, Great Barrington, Mass.	A Dec. 6, 1887 M Oct. 26, 1898

Name.	Address.	Date of Membership.
STEARNS, CHARLES K. *E.E.*	60 State Street, and 85 Westland Avenue, Boston, Mass.	A Aug. 6, 1889 M May 16, 1893
STEARNS, JOEL W., JR.	Treasurer, Mountain Electric Co., Box 1531, Denver, Col.	A June 20, 1894 M Nov. 20, 1895
STEBBINS, THEODORE	Engineer of Committee on Local Companies, General Electric Co., Schenectady, N. Y.	A July 9, 1889 M June 17, 1890
STEINMETZ, CHARLES P.	(*Manager.*) Electrician, General Electric Co., Schenectady, N. Y.	A Mar. 18, 1890 M April 21, 1891
STEPHENS, GEORGE	Societe des Establissements Postel-Vinay, 219 Rue de Vangirad, Paris, France	A June 20, 1894 M Dec. 18, 1895
STIERINGER, LUTHER	Electrical Expert, Beard Building, 120 Liberty St., New York City.	A June 8, 1887 M Nov. 1, 1887
STILLWELL, LEWIS B.	(*Vice-President.*) Electrical Director, Niagara Falls Power Company, and the Cataract Construction Co., Niagara Falls, N. Y.	A April 19, 1892 M Nov. 15, 1892
STORRS, PROF. H. A.	U. S. Assistant Engineer, Post Office Bldg.; residence, 45 William St., New London, Ct.	A Mar. 21, 1893 M Jan. 24, 1900
STOTT, HENRY G.	Electrical Engineer, Buffalo Gen'l Electric Co., Buffalo, N. Y.	A Sept. 25, 1895 M April 22, 1896
STRONG, FREDERICK G.	Box, 959, Hartford, Conn.	A Oct. 27, 1891 M July 18, 1899
TAINTOR, GILES	Sup't. Right of Way Department, New England Telephone and Telegraph Co, 125 Milk St; residence, 34½ Shepard St., Cambridge, Boston, Mass.	A June 26, 1891 M Dec. 16, 1891
TALTAVALL, THOS. R.	Associate Editor, *Electrical World, and Engineer*, 120 Liberty St., New York City.	A Jan. 20, 1891 M Oct. 27, 1891
TERRY, CHARLES A.	Lawyer, Westinghouse Electric and Mfg. Co., 120 Broadway, New York City.	A April 5, 1887 M May 17, 1887
THEBERATH, THEODORE E.	Chief Engineer, Yuba Electric Power Co, Marysville, Cal.	A Mar. 23, 1898 M June 24, 1898
THOMAS, BENJAMIN F.,	Professor of Physics, Ohio State University, Columbus, O.	A June 7, 1892 M Nov. 15, 1892
THOMSON, ELIHU	(*Past President*). Electrician, General Electric, and Thomson Electric Welding Companies, Lynn, Mass	A April 15, 1884 M April 21, 1891
THOMPSON, EDWARD P.	Consulting Electrician and Solicitor of Patents, 81 Fulton Street, New York City.	A April 15, 1884 M Dec. 3, 1889
THRESHER, ALFRED A.	Electrical Engineer and Proprietor Thresher Electric Co., Dayton, O.	A April 22, 1896 M June 24, 1898
THURNAUER, ERNST	Manager, Thomson-Houston International Elec. Co., 27 Rue de Londres, Paris, France.	A Oct. 14, 1887 M Dec. 6, 1887
TISCHENDOERFER, F. W.	Chief Electrical Engineer, Union Elektricitats Gesellschaft, Berlin, Germany.	A April 19, 1892 M Nov. 21, 1894
TRAFFORD, EDWARD W.	Electrical Engineer, Richmond Railway and Electric Co., Foot of 7th St., Richmond, Va.	A Feb. 21, 1894 M Dec. 19, 1894

Name.	Address.	Date of Membership.
UEBELACKER, CHAS. F.	General Manager, The Elmira Municipal Improvement Co., Elmira, N. Y.	A Feb. 7, 1890 M Nov. 15, 1893
UHLENHAUT, FRITZ, JR.	Whitestone, L. I.	A May 7, 1889 M Dec. 19, 1894
UPTON, FRANCIS R	Edison Laboratory, West Orange, N. J.	A May 17, 1887 M Mar. 15, 1892
VAIL, J. H	Engineer-in-Chief, Philadelphia Manufacturing Light and Power Co., and Edison Electric Light Co., 10th and Sansom Sts., Philadelphia, Pa.	A June 8, 1887 M Nov. 1, 1887
VANSIZE, WILLIAM B.	Solicitor of Patents, Expert in Patent Cases, 253 Broadway, New York City; residence, 210 Lincoln Road, Flatbush, Brooklyn, N. Y.	A April 15, 1884 M Oct. 21, 1884
VAN TRUMP, C. REGINALD	Engineer and Manager, Wilmington City Electric Co., Wilmington, Del.	A Feb. 5, 1886 M Feb. 21, 1894
WADDELL, MONTGOMERY	Consulting Engineer, 72 Trinity Place, New York City.	A Feb. 7, 1888 M May 1, 1888
WAIT, HENRY H.	Assistant Electrical Engineer, Western Electric Co., 4919 Madison Ave., Chicago, Ill.	A Sept. 20, 1893 M June 20, 1894
WALDO, LEONARD	Electrical Engineer, Secretary, The Waldo Foundry, 520 Stelle Ave., Plainfield, N. J.	A June 5, 1888 M Dec. 4, 1888
WALKER, SYDNEY F.	Consulting Electrical Engineer, Bloomfield Crescent, Bath, Eng.	A June 2, 1885 M May 17, 1887
WARING, JOHN	Perkins Electric Switch M'f'g. Co., 141 Washington St., Hartford, Conn.	A Dec. 16, 1890 M April 17, 1895
WARNER, ERNEST P.	Electrical Engineer, Western Electric Co.; residence, 402 Belden Ave., Chicago, Ill.	A Sept. 20, 1893 M June 20, 1894
WATERMAN, F. N.	Electrical Engineer, Westinghouse Electric and Mfg. Co., 120 Broadway, New York City.	A Feb. 21, 1893 M June 20, 1894
WEAVER, W. D.	(*Manager.*) Editor *Electrical World, and Electrical Engineer*; residence, 7 West 26th Street New York City.	A May 17, 1887 M May 17, 1887
WEBB, HERBERT LAWS	(*Manager.*) 18 Cortlandt St.; residence, 253 West 42d St., New York City.	A Oct. 21, 1890 M Dec. 16, 1890
WEEKS, EDWIN R.	V. P. and General Manager, 706 Wall St.; residence, 3408 Harrison St., Kansas City, Mo.	A Sept. 6, 1887 M Nov. 1, 1887
WELLER, HARRY W.	Electrical Engineer. 202 St. James St., Montreal, P. Q.	A Oct. 21, 1890 M Nov. 24, 1891
WESTON, EDWARD	(*Past President.*) Vice-President, Weston Electrical Instrument Co, 120 William St., and 645 High St., Newark, N. J.	A April 15, 1884 M Oct. 21, 1884

Name.	Address.	Date of Membership
WETZLER, JOSEPH	President, The Electrical Engineer Institute of Correspondence Instruction, 240 W. 23d St.; residence, 257 W. 104th St., N.Y. City.	A April 15, 1884 M Dec. 9, 1884
WHARTON, CHAS. J.	Palace Chambers, Westminster, London, Eng,	A Jan. 3, 1888 M May 1, 1888
WHEELER, SCHUYLER SKAATS, *Sc.D.* [Life Member.]	President, Crocker-Wheeler Co., 39 Cortlandt St., N. Y., and Ampere, N. J.; residence, 4 West 33d St., New York City.	A June 2, 1885 M Sept. 1, 1885
WHITE, WILL F.	Electrical Engineer, General Manager The Cincinnati Edison Electric Co., 220 W. 8th St., Cincin. O.	A Feb. 7, 1890 M July 27, 1898
WHITE-FRASER, GEO.	*Mem. Can Soc. C. E.*; 18 Imperial Loan Building, Toronto, Ont.	A Sept. 22, 1891 M Dec. 18, 1895
WIENER, ALFRED E.	Chief Instructor, The Electrical Engineer Institute, 240 W. 23d St., NewYork.	A May 16, 1893 M May 15, 1894
WILCOX, NORMAN T.	Sup't Colorado Electric Power Co., Colorado City, Col.	A May 21, 1895 M Jan. 22, 1896
WILKES, GILBERT	Consulting Electrical Engineer, 1112 Union Trust Building, Detroit, Mich.	A Jan. 7, 1890 M Mar. 18, 1890
WILLIS, EDWARD J.	Steam and Electrical Engineer, Virginia Electrical Railway and Development Co., 211 E. Franklin St., Richmond, Va.	A Nov. 30, 1897 M Feb. 28, 1900
WILLYOUNG, ELMER G.	E. G. Willyoung & Co., Electrical and Scientific Instruments, 82 Fulton St., New York City.	A Nov. 24, 1891 M Dec. 20, 1893
WILSON, CHARLES H.	General Manager, Southern Bell Telephone Co., 26 Cortlandt St., New York City.	A Nov. 24, 1891 M Feb. 16, 1892
WILSON, FREMONT	Consulting Engineer, 66 Maiden Lane (Telephone, 1651 Cortlandt) New York City; residence, 10 Hamilton Ave., Yonkers, N. Y.	A Mar. 6, 1888 M June 5, 1888
WILSON, HARRY C.	Supt. of P. O. Telegraph with the Government, Kingston, Jamaica, West Indies.	A Jan. 19, 1891 M June 7, 1892
WINCHESTER, A. E.	Electrical Commissioner and General Supt., City of South Norwalk Electric Works, also Consulting Engineer for Municipalities: residence, 4 Gerard Place, South Norwalk, Conn.	A June 8, 1887 M Nov. 1, 1887
WINSLOW, GEORGE HERBERT	Consulting Electrical Engineer, 82 & 83 Schmidt Building, 339 Fifth Ave., Pittsburgh, Pa,	A April 17, 1895 M Feb. 26, 1896
WOLCOTT, TOWNSEND	Electrician; residence, 329 Clinton St., Brooklyn, N. Y.	A Mar. 6, 1888 M Dec. 16, 1890
WOLVERTON, B. C.	Electrician, N. Y. & Pa. Telephone and Telegraph Co., Elmira, N. Y.	A Mar. 18, 1890 M Feb. 21, 1895
WORDINGHAM, CHAS. H.	City Electrical Engineer, The Manchester Corporation Electric Light Station, Dickinson Street, Manchester, England.	A July 27, 1898 M Oct. 26, 1898

Name.	Address.	Date of Membership.
WRIGHT, PETER	President, Virginia Electric Company, Norfolk, Va.	A May 16, 1889 M Jan. 16, 1895
WURTS, ALEXANDER JAY	Westinghouse Electric & Mfg. Co., Pittsburg, Pa.	A April 19, 1892 M Nov. 15, 1892
YOUNG, C. GRIFFITH	Engineer Construction, J. G. White & Co., 29 Broadway, New York.	A Jan. 3, 1889 M April 21, 1891
YOUNG, WALTER DOUGLAS	Electrical Engineer B. & O. R. R., Roland Park, Baltimore, Md.	A Apr. 26, 1899 M Jan. 24, 1900

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ASSOCIATE MEMBERS.

Name.	Address.	Date of Election.
ABBE, CLEVELAND	Professor of Meteorology. The Weather Bureau, residence 2017 I St., N. W. Washington, D. C.	Nov. 23, 1898
ABBOTT, HENRY	President, Calculagraph Co., 9 Maiden Lane, N. Y.; residence, 32 So. Clinton St., East Orange, N. J.	Apr. 28, 1897
ABELLA, JUAN	Director General of Public Lighting, Buenos Aires: residence, 691 Calle Bolivar, Buenos Aires, Argentine Republic.	Aug. 5, 1896
ADAE, CHAS. FLAMEN	67 Madison Ave., P. O. Box, 2809; New York City	Dec. 16, 1896
ADAMS, COMFORT A., JR.	Assistant Professor of Electrical Engineering, Harvard University, 13 Farrar St., Cambridge, Mass.	Jan. 17, 1894
ADAMS, ERNEST K.	Graduate Student, Columbia University; residence, 455 Madison Ave., New York City.	July 27, 1898
ADAMS, FRANK PIERCE	Electrician, Stockton Gas & Electric Co., residence, 329 E. Channel St., Stockton, Cal.	Feb. 15, 1899
ADAMS, JULIUS LE ROY	Chief Engineer, Hartford, Manchester & Rockville Tramway Co., Manchester, Conn.	Feb. 15, 1899
ADAMSON, DANIEL	Manager Joseph Adamson & Co., Hyde, Cheshire, England.	Feb. 26, 1896
AGNEW, CORNELIUS R.	18 William St.; residence, 23 West 39th St., New York City.	Mar. 21, 1894
ALEXANDER, HARRY	Electrical Engineer, General Manager and Vice Prest. Alexander-Chamberlain Electric Co., 25 West 33rd St., and 18 and 20 W. 34th St., Telephone 3767–38th, New York City.	April 21, 1891
ALLAN, JOHN	Full Partner, H. H. Kingsbury & Co., 54 Margaret St., Sydney, N. S. W.	Dec. 28, 1898
ALLEN, WYATT H.	Assistant Engineer, Benjamin, Hunt & Meredith, 331 Pine St., San Francisco, Cal.	Apr. 27, 1898
ALLEN, WALTER CUMMINGS,	Electrical Engineer of the Government of District of Columbia, District Building, residence, Victoria Flats, Washington, D. C.	June 24, 1898
ANDERSON, HENRY S.	General Manager and Electrician, United Electric Light Co., Springfield, Mass.	Jan. 16, 1895

Name.	Address.	Date of Election.
ANDREWS, WILLIAM, C.	*Electrical World and Engineer*, 120 Liberty St., New York. residence, Hotel Margaret, Brooklyn, N. Y.	May 21, 1895
ANTHONY, WATSON G.	Electrician, 32½ Webster St., Newark, N. J.	Feb. 24, 1891
APPLEYARD, ARTHUR E.	President, Natick Gas and Electric Co., Natick, Mass.	Aug. 5, 1896
ARCHBOLD, WM. K.	Westinghouse Electric and Mfg. Co. 120 Broadway, New York City.	June 20, 1894
ARCHER, GEO. F.	Electrical Engineer, 31 Burling Slip, New York City.	Nov. 21, 1894
ARMSTRONG, ALBERT H.	Electrical Engineer, General Electric Co., Schenectady, N. Y.	June 24, 1898
ASHLEY, FRANK M.	Consulting Engineer, 95 Liberty St.; residence, 63 Central Place, Brooklyn, N. Y.	Nov. 21, 1894
ATKINS, HAROLD B.	Assistant to H de B. Parsons, Consulting Engineer. 22 William St., residence, 40 W. 36th St., New York City.	June 23, 1897
ATWOOD, GEORGE F.	The Atwood Power and Speed Gage Company. 95 Liberty St., New York City: residence, Washington St., Hoboken, N. J.	Sept. 16, 1890
AUERBACHER, LOUIS J.	Electrical Engineer, 39 Cortlandt St., New York City.	Sept. 20, 1893
AUSTIN, SYDNEY B.	Construction Dep't New York Telephone Co., 32 Gold St., New York.	Sept. 25, 1895
BABSON, ARTHUR C.	Student, Electrical Engineering, University of California, Mechanics Building, Berkeley, Cala.	Mar. 28, 1900
BADEAU, ISAAC F.	General Electric Co.; residence, 144 Lafayette St., Schenectady, N. Y.	Feb. 26, 1896
BALCOME, HERBERT A.	With The B. F. Sturtevant Co., Jamaica Plain Station, Mass.	Oct. 27, 1897
BALDWIN, ALFRED DE V.	Selling Agent, Crocker-Wheeler Electric Co, P. O. Box, 267; residence, 206 W. 81 St., New York.	Aug. 13, 1897
BALDWIN, JAS. C. T.	Superintendent Bell Telephone Co., of Mo.; 10th and Olive Sts., St. Louis, Mo.	April 17, 1895
BALL, WM. D.	Consulting Electrical Engineer, Nagle and Ball, New York Life Building, Chicago, Ill.	Nov. 20, 1895
BALSLEY, ABE	Electrician, Terre Haute Electric Railway Co, 514 No. Center Street, Terre Haute, Ind.	Oct. 27, 1897
BANCROFT, CHAS. F.	Electrical Engineer, Massachussetts Electric Companies, 14 Kilby St., Boston, Mass.	Dec. 18, 1895
BANGS, CHAS. R.	Special Agent, American Telephone and Telegraph Co., 15 Dey St., New York.	Jan. 26, 1898

Name.	Address.	Date of Election.
BANKS, WILLIAM C.	Electrician, Gordon-Burnham Battery Co., 594 Broadway, New York City.	May 18, 1897
BARBOUR, FRED FISKE	Manager, Sales Department, Pacific District, General Electric Co.,Claus Spreckels Bldg.,San Francisco,Cal., and 1383 Franklin St., Oakland, Cal.	May 16, 1893
BARNES, CHAS. R.	City Electrician and Electrical Expert to State R. R Commission, Rochester, N. Y.	Aug. 13, 1897
BARNES, EDWARD A.	Electrical Expert, Fort Wayne Electric Co., Fort Wayne, Ind.	Sept. 20, 1893
BARNES, HOWELL HENRY	General Engineer, Mexican Electric Works Ltd. Apartado, 905, Mexico City.	Feb. 28, 1900
BARON, MAX D.	Outside Superintendent for Harry Alexander ; residence, 61 East 75th St., New York City.	Mar. 28, 1900
BARRY, DAVID	Electrician and Superintendent, Amherst Gas Co., Amherst, Mass.	Aug. 5, 1896
BARTON, ENOS M.	President Western Electric Co., 227 South Clinton St., Chicago, Ill.	July 12, 1887
BATES, FREDERICK C.	Electrical Engineer, General Electric Co., 44 Broad St., New York City.	Jan. 20, 1891
BATES, PUTNAM A.	Assistant Secretary, Crocker-Wheeler Co., 39 Cortlandt St.; residence, 113 W. 72d St., New York City.	Jan. 20, 1897
BAUGHER, E. C.	Engineer of Construction, Westinghouse Elec. & M'f'g Co., c/a Tokata & Co., Tokio, Japan.	Nov. 22, 1899
BAUM, FRANK GEORGE	219 First St., Pittsfield, Mass.	Nov. 22, 1899
BEAMES, CLARE F.	Ingeniero, Mexican General Electric Co., Apartado 403, City of Mexico.	May 21, 1895
BECHTEL, ERNEST J.	Superintendent Lighting and Construction, Toledo Traction Co., Toledo, O.	Mar. 24, 1897
BEEBE, MURRAY C.	Geo. Westinghouse, Exp. Dept.,Westinghouse E. and Mfg. Co., Amber Club, Pittsburg Pa.	Jan. 26, 1898
BEHREND, BERNHARD E.	Consulting Engineer, Box 604, Erie, Pa.	Jan. 24, 1900
BELL, ORA A.	Electrical Engineer, Western Electric Co., 22 Thames St., New York; residence, 921 St. Nicholas Ave., New York.	Aug. 5, 1896
BELLMAN, JOHN JACOB	Electrical Engineer, Westinghouse, Church, Kerr & Co., 26 Cortlandt St.; residence, 90 King St., New York, N. Y.	Dec. 28, 1898
BENNETT, EDWIN H., JR.	Electrician and Engineer, Diehl & Co., Elizabethport, N. J., and 19 West 33d St., Bayonne, N. J.	June 20, 1894

Name.	Address.	Date of Election.
BENNETT, JOHN C.	Electrician, General Electric Co., 44 Broad St. New York City.	Mar. 18, 1890
BENOLIEL, SOL. D., *B. S.*, *E. E.*, *A. M.*	Consulting Electrical Engineer, Adelphi College, Brooklyn, N. Y.	Oct. 21, 1896
BENTLEY, MERTON H.	Superintendent, New Telephone Co., 230 North Meridian St., Indianapolis, Ind.	Oct. 18, 1893
BERG, ERNST JULIUS	Engineer, General Electric Co.; residence, 243 Liberty St., Schenectady, N. Y.	Sept. 19, 1894
BERG, ESKIL	Electrical Engineer, Gen'l Electric Co., Schenectady, N. Y.	Nov. 20, 1895
BERGHOLTZ, HERMAN	Secretary and Treasurer, Ithaca Street Railway Co., Ithaca, N. Y.	April 2, 1889
BERLINER, EMILE	Inventor, Columbia Road, between Fourteenth and Fifteenth Sts., Washington, D. C.	April 15, 1884
BERRESFORD, ARTHUR W., *B. S.*, *M. E.*	Vice-Pres't and Supt. Iron Clad Resistance Co., Westfield, N. J.	May 15, 1894
BEST, A. T.	Electrical Engineer, Florida East Coast Hotel System, St. Augustine, Fla.	April 19, 1894
BETHELL, U. N.	General Manager, The New York Telephone Co., 15 Dey St., New York City.	Jan. 17, 1894
BETTS, HOBART D., *E. E.*	Room 517. 141 Broadway, New York, N. Y.; residence, Englewood, N. J.	Aug. 5, 1896
BEVERIDGE, EDMUND WALTER	Assistant Engineer, P. W. D. Bulsar, Surat D. Bombay Presidency, India.	Jan. 24, 1900
BIDDLE, JAMES G.	Electrical and Scientific Instruments, Drexel Bldg., Philadelphia, Pa.; residence, 417 West Price St., Germantown, Pa.	Aug. 5, 1896
BIJUR. JOSEPH, *A. B.*, *E. E.* [Life Member.]	34 Nassau St.; residence, 172 West 75th St., New York City.	May 15, 1894
BLACK, CHAS N.	Ford, Bacon & Davis, 149 Broadway, New York; residence, 31 Boyken St., Morristown, N. J.	April 19, 1890
BLACK, HOWARD D.	With Blackall & Baldwin, 39 Cortlandt St.; house, 340 Manhattan Ave., New York, N. Y.	Sept. 15, 1897
BLACKALL, FREDERICK, S.	P. O. Box, 267; office, 39 Cortlandt St.; residence, 51 Manhattan Ave., New York.	Sept. 15, 1897
BLACKWELL, FRANCIS O.	Engineer, Power and Mining Dept., General Electric Company, Schenectady, N. Y.	Mar. 28, 1900
BLAKE, HENRY W.	Editor, *Street Railway Journal*, 120 Liberty St., New York City.	Nov. 13, 1888
BLAKE, THEODORE W.	Electrical Engineer, 410 Bleecker St., residence. Engineers Club, 374 5th Ave., New York, N. Y.	Sept. 20, 1893

Name.	Address.	Date of Election.
BLANCHARD, CHARLES M.	1127 Betz B'ld'g., Philadelphia; residence, Winterburn, Pa.	Sept. 19, 1894
BLAXTER, GEO. H.	Room 44, Second National Bank Building, Pittsburg, Pa.	Sept 25, 1895
BLISS, WILLIAM L., *B. S., M. M. E.*	Electrical Engineer, 128 Front St., New York City; residence, 505 Throop Ave., Brooklyn, N. Y.	Mar. 21, 1894
BLIZARD, CHARLES	Manager Sales Department Electric Storage Battery Co., 19th St., and Allegheny Ave., Philadelphia; residence, 141 School Lane, Germantown, Pa.	Nov. 21, 1894
BLUNT, WILLAM W.	Engineer, Westinghouse Electric and M'f'g Co, Ltd., Westinghouse B'ld'g, Norfolk St., Strand, W. C., London, Eng.	Dec. 16, 1896
BOGEN, LOUIS E.	Instructor in Physics, University of Cincinnati; residence, 547 Hale Ave., Avondale, Cincinnati O.	May 16, 1899
BOGUE, CHARLES J.	Manufacturer and Dealer in Electrical Supplies, 206 Centre St., N.Y. City.	Dec. 3, 1889
BOHM, LUDWIG K., *Ph.D.*	Consulting Electrical and Chemical Expert, 320 Broadway, N. Y. City.	Nov. 15, 1892
BOLAN, THOMAS V.	Local Engineer, General Electric Co., 509 Arch St.; residence, 708 N. 40th St., Philadelphia, Pa.	Aug. 5, 1896
BONYNGE, PAUL	Attorney and Counsellor-at-Law firm of Latson & Bonynge, 141 Broadway, New York, residence, 104 Berkeley Place, Brooklyn, N. Y.	May 16, 1899
BOWMAN, JOSEPH H.	Material Agent, Ferro-carril de Chia. al Pac., Chihuahua, Mexico.	May 16, 1899
BOYD, JOHN DUNCAN	Electrician, Yuba Electric Power Co., Marysville, Cala.	Feb. 28, 1900
BOYLES, THOMAS D.	Electrical Engineer, General Electric Co.; residence, 406 Union St., Schenectady, N. Y.	Mar. 20, 1895
BRACKETT, BYRON B.	18 Third St., S.E., Washington, D. C.	Nov. 30, 1897
BRACKETT, PROF. CYRUS F.	Princeton, N. J.	April 15, 1889
BRADDELL, ALFRED E.	Electrical Inspector, Underwriters' Association, Middle Department, 316 Walnut St., residence. 7435 Boyer St., Mt. Airy, Philadelphia, Pa.	Sept. 1, 1890
BRADY, PAUL T.	Manager, Central N. Y. Agency, Westinghouse Electric and Mfg. Co., Syracuse, N. Y.	July 12, 1887
BRAGG, CHARLES A.	Manager Phila. Agency, Westinghouse Electric and Mfg Co., Land Title Building, residence, 3420 Powelton, Ave., Philadelphia, Pa.	Sept 20, 1893
BRAYSHAW, I.	Telegraph Inspector Great Southern Railway, City of Buenos Aires.	Aug. 5, 1896
BRIXEY, W. R.	Proprietor and Manufacturer, Day's Kerite Wire and Cables, 203 Broadway, New York City.	Sept. 20, 1893

Name.	Address.	Date of Election
BROICH, JOSEPH	Superintendent and Electrician, with F. Pearce, New York City; residence, 1622 8th Ave. Brooklyn, N.Y.	Jan. 17, 1894
BROILI FRANK	Electrical Engineer, California Elec. Works; residence, 154 Hickory Ave., San Francisco, Cal.	Feb. 23, 1898
BROPHY, WILLIAM	Chief Electrician to the Wire Department, 12 Old Court House, Boston; residence, 17 Egleston St., Jamaica Plain, Mass.	Mar. 5, 1889
BROWD, PAUL K.	Chief Engineer, The Russian Electric Company, "Union." Box 188, Kiev., Russia.	Feb. 15, 1899
BROWN, CHAS. L.	Gen'l Manager and Sec'y, Chicago Mutoscope Co., 1309 Monadnock Block, Chicago, Ill.	Nov. 20, 1895
BROWN, ELLIS EUGENE	Electrical Engineer, Philadelphia and Reading Railway Co., 7th and Franklin Streets, Reading, Pa.	May 16, 1899
BROWN, HUGH THOMAS	Mechanical and Electrical Engineer, with General Electric Co., 227 E. German St., Baltimore Md.	Jan. 26, 1898
BUCK, HAROLD W.	107 Union St., Schenectady, N. Y.	Jan. 16, 1895
BUCKINGHAM, CHAS. L.	Patent Attorney, Western Union Telegraph Co., 195 Broadway, P. O. Box 856, New York City.	April 15, 1884
BUNCE, THEODORE D.	President, The Storage Battery Supply Co., 239 E. 27th St., New York City.	May 20, 1890
BURGESS, CHAS. FRED'K.	Ass t Professor of Electrical Engineering, University of Wisconsin, residence, 609 Lake St., Madison, Wis.	Mar. 25, 1896
BURKE, JAMES	Klopstack Strasse, 15; Berlin, Germany.	May 16, 1893
BURKETT, CHAS. WATSON	General Inspector, Southern Bell Tel. & Tel, Co., Atlanta, Ga.	Aug. 23, 1899
BURNETT, DOUGLASS, *B.S.*	Edison Illuminating Co., Inspection Dept., 55 Duane St., New York City; residence, 42 Livingston St., Brooklyn, N. Y.	Feb. 21, 1893
BURROUGHS, HARRIS S.	Sprague Electric Co., 527 W. 34th St., New York; residence, 1416 Pacific St., Brooklyn, N. Y,	Nov. 30, 1897
BURT, BYRON T.	With Chattanooga Light & Power Co., Chattanooga, Tenn.	Sept. 25, 1895
BURTON, PAUL G.	Switchboard Dep't. Western Electric Co.; residence, 149 Lenox Ave, New York City.	Nov. 20, 1895
BUTLER, WILLIAM C.	President, The Puget Sound Reduction Co., Everett, Washington.	Mar. 21, 1893
BUYS, ALBERT	Electrical Engineer, The Rahway Electric Co., 105 Irving St., Rahway, N. J.	Feb. 7, 1890
BYRNS, ROBERT A.	Ohio Brass Company, 20 Broad Street, New York City.	Dec. 16, 1896

Name.	Address.	Date of Election.
CABOT, FRANCIS ELLIOTT	Supt. of Inspection and Electrician, Boston Board of Fire Underwriters, 55 Kilby Street Boston; residence, East Milton, Mass.	April 17, 1895
CABOT, JOHN ALFRED	124 W. 127th St., New York City.	May 16, 1893
CALDWELL, EDWARD	President Trade Paper Advertising Co, 150 Nassau St., New York City; residence, 409 E. 5th St., Plainfield, N. J.	Jan. 20, 1891
CALDWELL, FRANCIS CARY	Associate Professor of Electrical Engineering, Ohio State University, residence 8th and Michigan Aves., Columbus, O.	June 20, 1894
CAMPBELL, HENRY ARTHUR	Electrician, Jamaica Electric Light & Power Co., Ltd., 38 Harbor St, Kingston, Jamaica.	Sep. 27, 1899
CANFIELD, MILTON C.	Electrical Engineer, The Cleveland Contracting Co., 6th and Wyandotte Sts; residence, 18 Clinton St., Cleveland, O.	Feb. 21, 1893
CANFIELD, MYRON E.	Western Electric Co.; residence, 404 W. 44th St. New York City.	May 21, 1895
CAPUCCIO, MARIO	Raimondo & Capuccio, Consulting Engineers and Patent Agents, Piazza Statuto 15, Turin, Italy.	Dec. 20, 1893
CARICHOFF, E. R.	Electrical Engineer. Sprague Electric Co., Bloomfield, N. J.	Mar. 21, 1894
CARPENTER, CHAS. E.	Vice-President, Carpenter Enamel Rheostat Co., Bronxville, N. Y.	Aug. 5, 1896
CARTER, FREDERICK WILLIAM	Electrician, 38 Howard St.; residence, 82 Hampton Road, Birchfields, Birmingham, Eng.	Sept. 28, 1898
CARTY, JOHN J.	Chief Engineer, New York Telephone Co., 15 Dey St., New York City; residence, Short Hills, N. J.	April 15, 1890
CASE, WILLARD E.	196 West Genesee St., Auburn, N. Y.	Feb. 7, 1888
CASSIDY, JOHN	Superintendent Mutual Telephone Co., Honolulu, Hawaiian Islands, U.S.A.	Nov. 23, 1898
CHAPMAN, A. WRIGHT	160 Hicks St., Brooklyn, N. Y.	Mar. 25, 1896
CHAPPELL, WALTER E.	Electrician, on U. S. S. Chicago, U. S. Navy, Washington, D.C.: residence, Barnesville, O.	May 16, 1899
CHENEY, FREDERICK A.	Maple Avenue, Elmira, N. Y.	Oct. 1, 1889
CHILDS, SUMNER W.	Perth Electric Tramways, L't'd., Perth, Western Australia.	May 15, 1894
CHILDS, WALTER H.	Brattleboro, Vt.	Sept. 6, 1887
CLARK, CHAS. M., *E. E.*,	Clark & MacMullen, 42 E. 23d St., New York City.	April 22, 1896
CLARK, LEROY, JR.	Electrical Engineer of the Safety Insulated Wire and Cable Co., 229 West 28th St., residence, 208 West 85th St., New York City.	May 15, 1894

Name.	Address.	Date of Election
CLARK, WILLIAM J.	General Manager, Railway Dept. General Electric Co., 44 Broad Street, New York City.	April 22, 1896
CLARK, WM. EDWIN	With Clark & Mills, Engineers and Contractors, 57 Brattle St.; residence, 1440 Mass. Ave., Cambridge, Mass.	Aug. 23, 1899
CLEMENT, EDWARD E.	Patent Attorney and Electrical expert, Firm of Clement & Gharky, 1205-6 Stephen Girard B'ld'g., Phila., Pa.	May 18, 1897
CLEMENT, JOSEPH	Consulting Electricial Engineer, Messrs. Eckstein & Co., and Rand Mine, Box 149, Johannesburg. S. A. R.	Apr. 26, 1899
CLEMENT, LEWIS M.	Haywards Almeda Co., Cal.	April 21, 1891
CLOUGH, ALBERT L.	Box 114, Manchester, N. H.	Feb. 21, 1894
CODMAN, JOHN STURGIS,	Consulting Engineer. Associated with R. S. Hale, 31 Milk St.; residence, 57 Marlborough St., Boston, Mass.	Feb. 15, 1899
CODY, L. P.	Manager and Engineer, Grand Rapids Electric Co., 9 South Division St., Grand Rapids, Mich.	Aug. 5, 1896
COFFIN, CHAS. A.	General Electric Co., 180 Summer St., Boston, Mass.	Dec. 6, 1887
COHO, HERBERT B.	New York Manager Eddy Elec. Mfg. Co , 149 Broadway, New York City, residence, Mt. Vernon, N. Y.	Mar. 21, 1894
COLEMAN, WALTER H.	Supt. and Treasurer, Andover Electric Co., Andover, Mass.	Sept. 28, 1898
COLES, EDMUND P.	Ex-Resident Engineer, Manáos, Electric Lighting Co., Resident Engineer, Manáos Railway Co , Manáos, U. S. Brazil.	Oct. 23, 1895
COLLETT, SAMUEL D.	Eastern Manager, Elevator Supply and Repair Co., 136 Liberty St., New York City; residence, 156 Clinton St,, Brooklyn, N. Y.	Feb. 26, 1896
COMPTON, ALFRED G.	Professor of Applied Mathematics, College of the City of New York, 17 Lexington Ave.; residence, 40 W. 126th St, New York City.	Nov. 1 1887
COPELAND, CLEMENT A.	Acting Professor of Electrical Engineering, Stanford University, Cal.	June 23, 1897
COREY, FRED BRAINARD	Mechanical Engineer, Westinghouse Machine Co., East Pittsburg: residence, "The Colonial," Wilkinsburg, Pa.	Dec. 20, 1893
CORNELL, JOHN B.	Supt. of Construction, with Chas. L. Cornell, Hamilton, O.	Sept. 25, 1895
CORSON, WILLIAM R. C.	Superintendent, The Eddy Electric Mfg. Co., Windsor, Conn.	Jan. 17, 1893
CORY, CLARENCE L.	Professor of Electrical Engineering, University of California, Berkeley, Cal.	April 19, 1892

Name.	Address.	Date of Election.
COSGROVE, JAMES FRANCIS	Head of Locomotive Engineering Dept., International Correspondence School, 631 Madison Ave., Scranton Pa.	Nov. 23, 1898
CRAIN, JOHN JAY,	225 49th St., Newport News, Va.	Dec. 16, 1896
CRANDALL, CHESTER D.	Assistant Treasurer, Western Electric Co., 227 South Clinton St.; residence, 2821 Sheridan Road Chicago, Ill.	Sept. 27, 1892
CRANE, W. F. D.	Electrical and Mechanical Engineer, Columbia and Electric Vehicle Co., Hartford, Conn.; residence, 24 Reynolds Terrace, Orange, N. J.	Feb. 7, 1888
CRAWFORD, DAVID FRANCIS	Supt. Motive Power, Penn'a Co., Fort Wayne, Ind.	Sept. 25, 1895
CREAGHEAD, THOMAS J.	President and General Manager, Creaghead Engineering Co., 802 Plum St., Cincinnati, O.	Sept. 20, 1893
CREHORE, ALBERT C., *Ph.D.*	The Crehore Squier Intelligence Transmission Co., Brookside Park, Tarrytown, N. Y	Dec. 21, 1892
CRIGGAL, JOHN E.	Mechanician with Western Electric Co.; residence, 296 W. 11th St., New York City.	June 20, 1894
CROCKER, EBEN CLINCH	Electrical Engineer, American Ordnance Co., 29 Harriet Street, Bridgeport, Conn.	Jan. 26, 1898
CROSBY, OSCAR T.	Potomac Light and Power Co., 1417 G Street, Washington, D. C.	Mar. 18, 1890
CROWELL, ROBINSON	Chief Electrician, Pacific Power Co., 23 Stevenson St ; office, Laurel Hill Cemetery, San Francisco, Cal.	Dec. 28, 1898
CUMNER, ARTHUR B.	251 So. 12th St., Philadelphia, Pa.	Feb. 27, 1895
CUNNINGHAM, E. R.	Sup't Fort Dodge Light and Power Co., Fort Dodge, Iowa.	Jan. 22, 1899
CUNTZ, JOHANNES H.	325 Hudson St., Hoboken, N. J.	Mar. 5, 1889
CURRIE, N. M.	Santiago, Chili.	Feb. 15, 1899
DACUNHA, MANOEL IGNACIO	Manager of the Electrical Section, Emprera Industrial Gram-Para, Para, U. S. of Brazil.	May 16, 1898
DAGGETT, ROYAL BRADFORD	Electrical Engineer, Electric Storage Battery Co., Marquette Building, Chicago, Ill.	Jan. 25, 1899
DAMON, GEO. A.	With B. J. Arnold, Electrical Engineer, 1541 Marquette Building, Chicago, Ill.	Jun. 24, 1898
DAMON, GEO. B.	Farragut St., cor Wellesley Ave., Pittsburg, Pa.	June 23, 1897
DANA, R. K.	240 W. 74th St., New York City.	April 15, 1884
DANIELSON, ERNST	Consulting Electrician, Vestra Trädgårdsgatan 15 B, Stockholm, Sweden.	June 27, 1895
DARROW, ELEAZAR	Professor M. E. Dept. Washington Agr. College, Pullman, Wash.	Aug. 5, 1896

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Name.	Address.	Date of Election
DATFS, HENRY B,,	Professor of Electrical Engineering and Physics, Clarkson School of Technology, Potsdam, N. Y.	Dec. 28, 1898
DAVENPORT, GEORGE W.	61 Ames Bldg., Boston, Mass.	June 4, 1889
DAVIDSON, EDW. C.	Patent Lawyer, 141 Broadway, New York City.	Feb 7, 1890
DAVIS, ALBERT G.	Acting Manager, Patent Dep't, General Electric Co, Schenectady, N.Y.	Mar. 23, 1898
DAVIS, DELAMORE L.	Superintendent, Salem Electric Light and Power Co., 299 Lincoln Ave., Salem, O.	April 2, 1889
DAVIS, LESLIE FOSTER	Secretary and Manager, Jamaica Electric Light & Power Co., Ltd. 38 Harbor St., Kingston, Jamaica	Sept. 27, 1899
DAVIS, JOSEPH P.	Engineer, American Bell Telephone Co.,113 W. 38th St.,New York City.	April 15, 1884
DAVIS, W. J., JR.	Electrical Engineer, General Electric Co., Schenectady, N. Y.	Mar. 20, 1895
DEGEN, LEWIS	c/o. M. E. Levering, 1414 Chestnut St., Philadelphia, Pa.	Sept. 25, 1895
DEMPSTER, THOMAS	Electrical Engineer, General Electric Co., Schenectady, N. Y.	May 17, 1898
DE NORDWALL, CHARLES FLESCH,	Manager of the Export Department, Allgemeine Elektricitats-Gesellschaft, 22 Schiffbauerdamm, Berlin, N. W. Germany.	Sept. 27, 1892
DENHAM, JOHN	Electrician, Cape Goverement, Cape Town, South Africa	Jan. 24, 1900
DENTON, JAMES E.	Professor of Experimental Mechanics, Stevens Institute of Technology, Hoboken, N. J.	July 12, 1887
DEREDON, CONSTANT	Consulting Engineer. [Address unknown.]	May 18, 1897
DEXTER, FRANK H.	Draughtsman, Nassau Electric Co., 268 23d St.; residence, 391 8th St., Brooklyn, N. Y.	June 24, 1898
DEY, HARRY E.	711 E. 136th St., New York City.	Dec. 19, 1894
DICKERSON, E. N.	Attorney-at-Law, 141 Broadway; residence 64 E. 34th St., New York City.	April 15, 1884
DIETERICH, FRED. G.	Solicitor of Patents and Mechanical Expert, 602 F Street, Washington, D. C.	July 18, 1899
DINKEY, ALVA C.	Supt. Electric Dept., Homestead Steel Works, Munhall, Pa.	Feb. 17, 1897
DOBBIE, ROBERT S.	Electrical Engineer, Riding Mill-on-Tyne, Northumberland, Eng.	Feb. 5, 1889
DOHERTY, HENRY L.	40 Wall Street, New York City.	Sept. 28, 1898
DOOLITTLE, CLARENCE E.	Manager and Electrician, Roaring Fork Electric Light and Power Co., Aspen, Colo.	May 15, 1894
DOOLITTLE, THOMAS B.	Engineering Department, American Bell Telephone Co., 125 Milk St., Boston, Mass.	May 16, 1893

Name.	Address.	Date of Election
DOREMUS, CHARLES AVERY	*M.D. Ph.D.* 59 W. 51st St., New York City.	July 7, 1884
DOWNES, LOUIS, W.	Vice-President and General Manager, The D. & W. Fuse Co, 53 Aborn St., Providence, R. I.	Nov. 22, 1899
DOWNING, P. M.	Electrician, Standard Mining Co., Bodie, Mono Co., Cal.	June 24, 1898
DRESSLER, CHARLES E.	17 Lexington Ave., New York City.	Dec 16, 1890
DRYSDALE, DR., W. A.	Consulting Electrical Engineer, Hale Building, Philadelphia, Pa.	Sept. 19, 1894
DUBOIS, TUTHILL,	2195 Pitkins Ave., Brooklyn, N. Y.	Aug. 23, 1899
DUNCAN, JOHN D. E.	Electrician Consolidated Railway, Electric Light and Eng. Co., 100 Broadway, New York; residence, 18 Sidney Place, Brooklyn, N. Y.	Mar. 20, 1895
DUNCAN, THOMAS	Manager, Meter Dep't, Siemens & Halske Electric Co., Grant Works, Chicago; residence, 110 North Central Ave., Austin, Ill.	Oct. 17, 1894
DUNN, CLIFFORD E.	Patent Attorney, 1029 Park Row Bldg, New York City, residence, 12-a Monroe St., Brooklyn, N. Y.	Feb. 15, 1899
DUNN, KINGSLEY G.	British Columbia Electric Railway, L't'd., 37 John Street, Victoria, B. C.	Oct. 17, 1894
DURANT, EDWARD	Chief Electrical Engineer, Manhattan State Hospital of the State of New York, Ward's Island, N. Y.; residence, 115 East 26th St., New York City.	Nov. 15, 1892
DURANT, GEO. F.	Vice-Pres't Bell Telephone Co., of Mo., Telephone Building, St. Louis, Mo.	April 15, 1884
DYER, ERNEST I.	Engineer and Manager of the Engineering Department of the American Trading Co., Box 28, Yokohama, Japan.	Jan. 25, 1899
EDDY, H. C.	Electrical Engineer and Contractor, Lees Building, Chicago, Ill.	June 20, 1894
EDMANDS, I. R.	Electrical Engineer, Union Carbide Co., residence, 315 Buffalo Ave., Niagara Falls, N. Y.	June 23, 1897
EDWARDS, JAMES P.	Consulting Electrician, Augusta, residence, Montesano, Summerville, Ga.	April 19, 1892
EDWARDS, CLIFTON V.	Attorney-at-Law and Solicitor of Patents, 220 Broadway, New York.	Nov. 22, 1899
EGLIN, WM. C. L.	Electrical Engineer, N., E. cor 10th and Sansom Sts., residence, 4230 Chester Ave., Philadelphia, Pa.	Sept. 19, 1894
EKSTROM, AXEL	Electrical Engineer, General Electric Co.; Schenectady, N. Y.	June 17, 1890
ELLARD, JOHN W.	Treasurer, Edion Electric Illuminating Co., 15 South Street, Baltimore, Md.	June 23, 1897

Name.	Address.	Date of Election.
ELIAS, ALBERT B.	1310 Washburn Street, Scranton, Pa.	Jan. 26, 1898
ELLIS, JOHN	Manager, The Lonsdale Co 's Electric Light Plant, Lonsdale, R. I.	Apr. 26, 1899
ELLIS, R. LAURIE	Electrician, 803 Broad St., residence 215 Monument St., Augusta, Ga.	April 26, 1899
ELMER, WILLIAM, JR.	General Foreman; Electric Car Service West Jersey and Seashore R. R. Co., residence, 36 N. Vernon Ave., Atlantic City, N. J.	Mar. 18, 1890
ELY, WM. GROSVENOR, JR.	Ass't Supt. Construction, General Electric Co., 849 Union Street, Schenectady, N. Y.	Mar. 21, 1893
EMERICK, LOUIS W.	Electrical Engineer, The Solvay Process Co., Syracuse, N. Y.; residence No. 14, The Kenyon, Harrison St., Syracuse, N. Y.	Aug. 13, 1897
ENDE, SIEGFRIED H.	121 E. 77th St., W. New York City.	Jan. 17, 1894
ENTZ, JUSTUS BULKLEY	Electrical Engineer, Electric Storage Battery Co., 19th St., and Allegheny Ave., Philadelphia, Pa.	Jan. 7, 1890
ERICKSON, F. WM.	Electrical Engineer, The Erickson Electric Equipment Co., 71 Federal St., Boston, Mass.	Sep. 19, 1894
ESTERLINE, J. WALTER	Instructor Electrical Engineering, Purdue University, residence, 124 Grant St., Lafayette, Ind.	Mar. 28, 1900
ESTY, WILLIAM	Associate Professor of Electrical Engineering, University of Illinois, Urbana, Ill.	Mar. 20, 1895
ETHERIDGE, LOCKE	Mechanical Engineer, 1001 Monadnock B'ld'g, 44 E. 50th St., Chicago, Ill.	Oct. 17, 1894
EVANS, CLEMENT W.	Electrical Engineer, American Engineering Co., Box 2100 Mexico City.	Feb. 28, 1900
EVANS, PAUL H.	Chief Engineer Mexican General Electric Co., Apartado 403 Mexico City.	Jan. 24, 1900
EYRE, MANNING K.	c/o W. L. R. Emmet, Schenectady, N. Y.	Oct 17, 1894
FARNSWORTH, ARTHUR J.	Chief Engineer, East Chester Electric Co., 3 Depot Place, Mount Vernon; residence, 30 Beechwood Ave., New Rochelle, N. Y.	Jan. 16, 1895
FIELDING, FRANK E. [Life Member.]	Chemist and Assayer, Virginia City, Nev.	Sept. 6, 1887
FINNEY, JOHN C.	Cashier, Wisconsin Trust Co.; residence, 34 Prospect Ave, Milwaukee, Wis.	Dec. 28, 1898
FIRTH, WM. EDGAR	Chief Engineer, The Midvale Steel Co.; Nicetown, Philadelphia; residence, 7203 Boyer St., Germantown, Pa.	Mar. 25, 1896
FISH, FRED. ALAN	Assistant in Electrical Engineering, Ohio State University, 229 West 11th Avenue, Columbus, Ohio.	Mar. 28, 1900
FISHER, HENRY W.	Electrician and Director of Elec. and Chem. Laboratories; The Standard Underground Cable Co., Pittsburg, Pa.	Jan. 16, 1895

Name.	Address.	Date of Election.
FITZHUGH, WM. H.	Supt. Bay City Electric Plant, Bay City, Mich.	April 27, 1898
FLATHER, JOHN J.	Professor of Mechanical Engineering, University of Minnesota; residence, 316 10th Ave., S. E., Minneapolis, Minn.	April 19, 1892
FLEMING, JOHN BRECKENRIDGE,	M. M., and Elec. Engineer, Silver King Mill, Park City, Utah.	April 27, 1898
FLIESS, ROBERT ANTON	201 W. 55th St., New York City.	Mar. 23, 1898
FLOOD, J. F.	Sup't Steubenville Traction Co., Steubenville, O.	Mar. 18, 1890
FLOY, HENRY	Consulting Electrical and Mechanical Engineer, 220 Broadway, New York City.	May 17, 1892
FOG, CARL F.	Electrician, General Electric Co.; residence, 29 Commercial St., Lynn, Mass.	Mar. 28, 1900
FOOTE, THOS. H.	Electrical Engineer, Westfield, N. J.	April 21, 1891
FORBES, FRANCIS	Lawyer, 32 Nassau St., New York City.	Sept. 16, 1890
FORBES, GEORGE	Electrical Engineer, 34 Great George St., London, Eng.	Feb. 21, 1894
FORD, ARTHUR HILLYER,	*E. E.* Engineering Dep't., Western Electric Co.; residence, 296 Manhattan Ave., New York City.	Mar. 24, 1897
FORD, FRANK R., *M. E.*	Consulting Engineer, Ford, Bacon & Davis, 149 Broadway, New York City.	Mar. 25, 1896
FORD, WM. S.	Assistant to Chief Engineer, The American Bell Telephone Co., room 73, 125 Milk St., Boston, Mass.	June 7, 1892
FRANCISCO, M. J.	President and General Manager, Rutland Electric Light Co., Rutland, Vt.	June 17, 1890
FRANK, GEO. W., JR.	c/o. J. G. White & Co., 29 Broadway, New York City.	Sept. 28, 1898
FRANKENFIELD, BUDD	Instructor in Electrical Engineering, University of Wisconsin, 609 Lake St., Madison, Wis.	Feb. 17, 1897
FRANKLIN, W. S.	Professor of Physics and Electrical Engineering, Lehigh University, South Bethlehem, Pa.	Jan. 22, 1896
FRANTZEN, ARTHUR	Electrical Engineer and Contractor, 225 Dearborn St., residence, 662 N. Irving Ave., Chicago, Ill.	Feb. 21, 1894
FRENCH, THOMAS, JR.	*Ph.D.* 713 E. Ridgeway Ave., Cincinnati, O.	Sept. 20, 1893
FRENYEAR, THOMAS C.	Westinghouse Electric and Mfg. Co., 782 Ellicott Sq., Buffalo, N. Y.	Sept. 25, 1895
FRIEDLAENDER, EUGENE	Electrician, Carnegie Steel Company, Duquesne, Pa.	Nov. 20, 1895

Name.	Address.	Date of Election
FROST, JOSEPH W.	Secretary, National Automatic Fire Alarm, 335 Broadway, New York City.	Mar. 20, 1895
FRY, DONALD HUME	Snoqualmie Falls Power Co., Snoqualmie, Wash.	Nov. 23, 1898
GALLAHER, EDWARD B.	The Pneumatic Supply and Equipment Co., 120 Liberty St.; residence, 137 W. 116th St., New York City.	Jan. 19, 1895
GALLATIN, ALBERT R.	Student at Columbia University, residence 58 W. 55th St., New York City.	Mar. 23, 1898
GANZ, ALBERT F.	Assistant Professor, Physics and Applied Electricity. Stevens Institute; residence 612 River St., Hoboken, N. J.	April 26, 1899
GARRELS, W. L.	Garrels & Freeman. Consulting Engineers, Franklin Bank B'ld'g.; residence, 4531 West Pine Boulevard, St. Louis, Mo.	Mar. 20, 1895
GARFIELD, ALEX. STANLEY	Engineer, Cie Thomson-Houston, 27 Rue de Londres, Paris, France.	Jan. 26, 1898
GAYTES, HERBERT	Electrical Engineer, 395 Vernon St., Oakland, Cal.	Mar. 23, 1898
GHERARDI, BANCROFT, JR.,	Engineer, Traffic Dept. New York Telephone Co.; 15 Dey St., New York City; residence, 33 Evergreen Place, East Orange, N. J.	June 27, 1895
GIBSON, GEO. H.	Assistant Editor Engineering News, 220 Broadway; residence, 136 E. 71st St., New York City.	Nov. 22, 1899
GILLILAND, E. T.	Pelham Manor, N. Y.	April 15, 1884
GILMORE, LUCIEN H.	Prof. of Physics and Electrical Engineering, Throop Polytechnic Institute, Pasadena, Cal.	Mar. 20, 1895
GLADSON, WM. N.	Professor of Electrical Engineering, University of Arkansas, Fayetteville, Ark.	Dec. 28, 1898
GLADSTONE, JAMES WM.	Manager, Edison Mfg. Co., 110 East 23d St., New York City; residence, West Orange, N. J.	April 18, 1894
GODDARD, CHRIS. M.	Secretary New England Insurance Exchange. Sec'y Underwriters' National Electric Ass'n, 55 Kilby St,, Boston, residence, 11 Glenwood Ave., Newton Centre, Mass.	April 22, 1896
GOLDMARK, CHAS. J.	Consulting Electrical Engineer, 29 Broadway. Tel. 2729 Broad, New York City.	June 5, 1888
GOODMAN, WM. GEO. TOOP	Electrical Engineer, Tramway Construction under N.S W. Government, Public Woks Dep't; residence, 86 Bondi Road. Sydney, N.S.W.	Aug. 23, 1899
GORDON, REGINALD	Instructor in Physics, Columbia University, residence, 315 W. 71st St., New York City.	Feb. 24, 1891
GORRISSEN, CH.	With Siemens & Halske, Franklinstrasse 29, Charlottenburg, Ger.	Mar. 25, 1896

Name.	Address.	Date of Election.
GORTON, CHARLES	Civil Engineer, Belmont, N. Y.	Nov. 12, 1889
GRANBERY, JULIAN H.	*Jun. Am. Soc. C. E.;* residence, Elmora, Elizabeth, N. J.	Aug. 5, 1896
GRANT, LOUIS T.	Vice-President and General Manager, Hawaiian Automobile Co., Box 536, Honolulu, H. I.	Nov. 22, 1899
GRAVES, CHAS. B.	Sao Paulo Railway, Light and Power Co., Sao Paulo, U. S. Brazil.	Sept. 15, 1897
GREENLEAF, LEWIS STONE	American Bell Telephone Co., 30 Farnsworth St., Boston, Mass.	Aug. 5, 1896
GREEN, ELWYN CLINTON	With Commercial Electric Co.: residence, 1710 Prospect St., Indianapolis, Ind.	Mar. 25, 1896
GREENWOOD, FRED. A.	Secretary California Electric Works, 409 Market St., San Francisco, Cal.	April 28, 1897
GREENWOOD, GEORGE	Electrical Engineer and Superintendent, Jalapa Railway and Power Co., Jalapa, V. C., Mexico.	Jan. 24, 1900
GREGG, TOM HOWARD	Supt. Electrical Construction, U. S. Light House Board, Tompkinsville, S. I., N. Y.; residence, 6 Wall St., St. George, S. I.	Mar. 22, 1899
GRIFFEN, JOHN D.	Inventor, Electric Conduit and Electric Signaling Apparatus, 60 Broadway; residence, 304 West 90th St., New York.	Aug. 13. 1897
GRIFFES, EUGENE V.	Electrical Engineer, 121 E. 4th Street, Los Angeles, Cal.	Feb. 26, 1896
GRIFFIN, CAP'T EUGENE	First Vice-President, General Electric Co., 44 Broad St., New York City.	Feb. 7, 1890
GROWER, GEORGE G.	Electrician and Chemist, Ansonia Brass and Copper Co., Ansonia, Conn.	Mar. 18, 1890
GUY, GEORGE HELI	Secretary, The New York Electrical Society, 120 Liberty St, New York City.	May 16, 1893
HADLEY, ARTHUR L.	Electrical Engineer, Fort Wayne Electric Works, residence, 252 W. De-Wald St., Fort Wayne, Ind.	Oct. 17, 1894
HADLEY, FRED'K W. [Life Member.]	Electrical Eng'r, Arlington Heights, Mass.	Aug. 5, 1896
HAKONSON, CARL HAROLD	Electrical Engineer, with the Union Elektricitäts Gesellschaft, Dorotheeastr 43, Berlin, N.W., Ger.	Sept. 25, 1895
HALL, EDWARD J.	Vice-President and General Manager, American Telephone and Telegraph Co., 15 Dey St., New York City.	April 18, 1893
HALL, FRED'K A.	c/o W. S. Wadsworth, 824 Broadway, Chelsea, Mass.	Aug. 23, 1899
HALL, J. P.	Electrical Contractor, 22 Thames St.; residence, 200 W. 136th St., N. Y.	Aug. 5, 1896

Name.	Address.	Date of Election
HALLBERG, J. HENRY	Electrician, General Incandescent Arc Light Co., 572 First Ave., New York City.	Aug. 23, 1899
HAMERSCHLAG, ARTHUR A.	Consulting Engineer, 100 Maiden Lane, New York City.	Mar. 25, 1896
HAMILTON, JAMES	Patent Law Specialist. 53 State St., Boston, residence, 205 Crafts St., Newtonville, Mass.	Nov. 23, 1898
HAMMATT, CLARENCE S.	Manager, Jacksonville Electric Light Co., Jacksonville, Fla.	Sept. 20, 1893
HANCOCK, L. M.	Supt., Nevada County Electric Power Co., P. O. Box 151, Nevada City, Cal.	May 19, 1891
HANSON, ARTHUR JAMES	Lawrence & Hanson, 3 Wynyard St, residence, Drunnmoyne, Sydney, N. S. W.	Nov. 22, 1899
HARDING, H. McL.	20 Broad Street, New York City.	May 24, 1887
HARDY, CARL EARNEST	Student, Cornell University, residence 804 E. Seneca St, Ithaca, N.Y. and 704 N. Broad St., Rome, Ga.	Dec. 27, 1899
HARRIS, GEORGE H.	Electrical Engineer, Birmingham Railway and Electric Co., Birmingham, Ala.	June 20, 1894
HARTMAN, HERBERT T.	2nd Vice-President and Chief Engineer, 1406 Land Title B'ld'g., residence, 3135 Clifford St., Philadelphia, Pa.	Mar. 21, 1893
HARVEY, ROBERT R. [Life Member.]	10 So. Franklin St., Wilkes-Barre, Pa.	Sept. 25, 1895
HATHAWAY, JOSEPH D., JR.	Assistant in Cable Dep't Western Electric Co., 57 Bethune St., N. Y. City.	Aug. 5, 1896
HATZEL, J. C.	Firm Hatzel and Buehler, 114 Fifth Ave., residence, 1231 Madison Ave., New York City.	Sept. 3, 1889
HEALY, LOUIS W.	Treasurer, East Liverpool Railway Co., East Liverpool, Ohio.	June 26, 1891
HEDENBERG, WM. L.	Manager and Editor, *Electricity*, 136 Liberty Street, New York City.	Nov. 21, 1894
HEFT, N. H.	Chief of Electrical Dep't N.Y.N.H. & H. R. R., New Haven: residence, Bridgeport, Conn.	Aug. 23, 1899
HELLICK, CHAUNCEY GRAHAM	Chicago Telephone Co., 203 Washington St, Chicago, Ill.	Jan. 26, 1898
HENDERSON, ALEX.	Electrician, Sprague Electric Co., residence, 104 W. 115th St. N. Y.	Nov. 30, 1897
HENDERSON, HENRY BANKS	Riverside, Cal.	May 21, 1895
HENRY, GEO. J., JR.,	Engineer for The Pelton Water Wheel Co., 143 Liberty St. New York and 121 Main St., San Francisco, Cal.	April 27, 1898
HENRY, LEWIS WARNER	Assistant in Engineering Department, Mexican General Electric Co, Mexico City.	Feb. 28, 1900
HERDT, LOUIS A.	Lecturer on Electrical Engineering, McGill University, Montreal, Canada.	May 16, 1899

Name.	Address.	Date of Election
HERMESSEN, JOHN LOUIS	83 Cannon St., London, E. C., England.	Jan. 20, 1897
HESSENBRUCH, GEORGE S.	*E.E. Ph.D* Ass't Engineer to Sup't of Structure, 205 Union Station, Terminal R. R., residence, 514 N. Spring Ave., St. Louis, Mo.	June 27, 1895
HEWITT, CHARLES E.	Electrician, Hyer-Sheehan Electric Motor Co., 139 Chamber St., Newburgh, N. Y.	Sept. 25, 1895
HEWITT, WILLIAM R.	Superintendent, Fire Alarm and Police Telegraph, 9 Brenham Place, San Francisco, Cal.	May 15, 1894
HEWLETT, EDWARD M.	Engineer, General Electric Co., residence, 19 University Place, Schenectady, N. Y.	May 19, 1891
HILDBURGH, WALTER LEO	Student, Columbia University; c/o D. H. Hildburgh, Hotel Normandie, New York.	Dec. 28, 1898
HILL, ERNEST ROWLAND	Electrical Engineer, Westinghouse E. & M. Co., Pittsburg, Pa.	Jan. 25, 1899
HILL, GEORGE, *C.E.*	Consulting Engineer, 150 5th Ave., Tel. 2326 18th., New York City.	April 19, 1892
HILL, G. HENRY	Engineer, Sprague Electric Co., 527 W. 34th St., residence, 16 Prospect St., East Orange, N. J.	Jan. 25, 1899
HILL, H. P.	Washington Loan and Trust Building, Washington, D. C.	Nov. 18, 1897
HILL, NICHOLAS S., JR.	General Manager, Charleston Consolidated Railway, Gas and Electric Co., Charleston, S. C.	Aug. 5, 1896
HOAG, GEO. M.	City Electrician, City of Cleveland, 113 City Hall; residence, 317 Hough Ave., Cleveland, O.	April 28, 1897
HODGE, WILLIAM B.	Electrical Engineer, Queen & Co., 707 Spruce St., Philadelphia, Pa.	Dec. 28, 1898
HOFFMANN, BERNHARD	New York Telephone Co., 15 Dey St., residence, 12 W. 18th St., New York City.	Nov. 23, 1898
HOLBERTON, GEORGE C.	Chief Engineer and Electrician, Bangkok Electric Light Syndicate, Bangkok, Siam.	May 15, 1894
HOLBROW, HERMAN L.	With New York Telephone Co.; residence, 265½ West 22d St., New York City.	Mar. 24, 1897
HOLMES, GWYLLYN R.	Holmes-Rose Electric Co., No. 215 Calvert St., residence 2842 Parkwood Ave., Baltimore, Md.	Jan. 24, 1900
HOLT, MARMADUKE BURRELL	Mining and Electrical Engineer, Silverton, Col.	April 15, 1890
HOMMEL, LUDWIG	Supt. of Construction, Standard Underground Cable Co., 1225 Betz Building, Philadelphia, Pa.	Jan. 20, 1897
HOOD, RALPH O.	Electrical Engineer, Danvers, Mass.	April 18, 1894
HOPEWELL, CHAS. F.	Inspector of Wires, Supt. of Lamps, Fire Alarm and Police Telegraph, City of Cambridge, City Hall; residence, 82 Magazine St., Cambridgeport, Mass.	Aug. 13, 1897

Name.	Address.	Date of Election.
HOPKINS, NEVIL MONROE	Electrical Engineer, 1730 I Street, Washington, D. C.	Nov. 20, 1895
HOPKINS, N. S.	Designing Engineer. General Electric Co., Lynn, Mass.	April 27, 1898
HORN, HAROLD J.	Electrical Engineer, John A. Roebling's Sons' Co ; residence, 36 W. State St.. Trenton, N. J.	Mar. 22, 1899
HOSMER, SIDNEY	Electrical Engineer Boston Electric Light Co , Ames Building, Boston, Mass.	May 18, 1897
HOWSON, HUBERT	Patent Lawyer, 38 Park Row, New York City.	June 8, 1887
HUBBARD, ALBERT S.	Gould Storage Battery Co., Astor Court B'ld'g, 25 W. 33rd St., residence, Belleville, N. J.	Nov. 20, 1895
HUBBARD, WILLIAM C.	Vice-President, Electric Arc Light Co., Sales Manager Manhattan General Construction Co., 11 Broadway, New York, residence, 427 West 7th St., Plainfield, N. J.	April 18, 1894
HUBLEY, G. WILBUR	Superintendent and Electrical Engineer, Louisville Electric Light Co.; residence, 1107 Third Ave, Louisville, Ky.	Sept. 19, 1894
HUBRECHT, DR. H. F. R.	Director, Nederlandsche Bell Telephone Co., Amsterdam, Holland.	Oct. 4, 1887
HUDSON, JOHN E.	President, The American Bell Telephone Co., 125 Milk St., Boston, Mass.	Dec. 20, 1893
HUGGINS, N. W.	Salesman, etc., General Electric Co., Seattle, Wash.	Aug. 5, 1896
HUGUET, CHAS. K.	Electrical Engineer, 731 Jackson Boulevard, Chicago. Ill.,	June 27, 1895
HULL, S. P.	Inspector of Signals, N. Y. C. & H. R. R. R. Co., Spuyten Duyvil, residence 232 Warburton Ave., Yonkers, N. Y.	May 19, 1896
HULSE. WM. S.	Electrical Engineer, with Union Elektricitäts Gesellschaft, Berlin, Germany.	Mar. 25, 1896
HUMPHREYS, C. J. R.	Manager, Lawrence Gas Co., and Edison Electrical Ill. Co., Lawrence, Mass.	Sept. 6, 1887
HUNT, ARTHUR L.	Harrisburg Foundry and Machine Works, 203 Broadway, New York City.	Sept. 19, 1894
HUNT, A. M.	Consulting Engineer, 331 Pine Street, San Francisco, Cala.	Feb. 28, 1900
HUNTLEY, CHAS. R.	General Manager, Buffalo General Electric Co., 40 Court St., Buffalo, N. Y.	Sept. 25, 1895
HUTTON, CHAS. WILLIAM	Chief Electrician, Sacramento Electric Gas and Railway Co., Sacramento. Cal.	Feb. 15, 1899
HUTCHINSON, FREDERICK L.	Electrical Engineer, Westinghouse Electric and Mfg. Co., Pittsburg, Pa.	June 20, 1894
HYDE, J. E. HINDON	Patent Lawyer, 120 Broadway, New York City.	Jan. 24, 1900

Name.	Address.	Date of Election.
IDELL, FRANK E.	Havemeyer Building, 26 Cortlandt St., New York City.	July 12, 1887
IHLDER, JOHN D.	Electrical Engineer, Otis Electric Co., Yonkers, N. Y.	Oct. 2, 1888
IIJIMA ZENTARO,	Electrical Engineer. 89 Shinhanacho, Hongo Tokyo, Japan.	Jan. 22, 1896
INGOLD, EUGENE	Consulting Engineer and Expert, 1669 Second Ave., Pittsburg, Pa.	April 18, 1894
INSULL, MARTIN J.	2d Vice-President and General Manager, General Incandescent Arc Light Co New York, residence, 262 W. 83d St., New York City.	Nov. 22, 1899
INSULL, SAMUEL	President, Chicago Edison Co., 139 Adams St., Chicago, Ill.	Dec. 7, 1886
IRVINE, DREW W.	[Address unknown.]	Sept 25, 1895
IWADARE, KUNIHIKO	Electrician, Nippon Electric Company, 2 Mita Shikokumachi Shibaku, Tokyo, Japan.	Sept. 20, 1893
JACKSON, E. D.	Cuyahoga Telephone Co., 803 Electric B'ld'g, residence, 508 Prospect St., Cleveland, O.	Nov. 22, 1899
JACKSTON, WM. STEELL	4th Assistant Examiner, Patent Office; residence, 325 Spruce St., N. W., Washington, D. C.	April 22, 1896
JAEGER, CHARLES L.	Inventor, Maywood, N. J., Electric Recording Ship Apparatus, Laboratory, 132 Mulberry St., New York, N. Y.	Dec. 20, 1893
JAMES, HENRY DUVALL, *B. S., M. E.*	Engineering Dep't, Otis Bros. & Co, residence, 100 Buena Vista Ave., Yonkers, N. Y.	Nov. 23, 1898
JAQUAYS, HOMER M.	Lecturer in Mechanical Engineering, McGill University, residence, 862 Sherbrooke St., Montreal, Quebec.	Dec. 27, 1899
JOHNSON, ALBERT C.	Superintendent and Electrician, Electric Light & Water Works, Box 7, Willmar, Minn.	May 16, 1899
JOHNSON, HOWARD S.	Engineer and Sales Agent, Morgan-Gardner Electric Co.; residence, 70 Jefferson Ave., Columbus, O.	Mar. 22, 1899
JOHNSON, THOS. J	Counsel in Patent Causes, 66 Broadway, New York City.	May 16, 1896
JOHNSTON, W. J.	Greenwich, Conn.	April 15, 1884
JONES, ARTHUR W.	Care of Gibbs, Bright & Co., Melbourne, Australia.	Oct. 17, 1894
JONES, FORREST R.	Professor of Drawing and Machine Design, Worcester Polytechnic Institute, residence, 3 State St., Worcester, Mass.	May 20, 1890
JONES, G. H.	Agent, General Electric Co., Casilla 1317 D Santiago, Chile.	April 17, 1895
JONES, HENRY C.	Member of Firm, the Electric Construction and Supply Co., Montgomery, Ala.	Mar. 20, 1895

Name.	Address.	Date of Election.
JONES, M. E.	Chief Engineer, St. Lawrence State Hospital, Ogdensburg, N. Y.	Oct. 27, 1897
JOSLYN, HOWARD.	Assistant Engineer, Snoqualmie Falls Power Co., Seattle, Wash.	May 17, 1898
JUDSON, WM. PIERSON	Deputy State Engineer, of New York, Albany: residence, Oswego, N. Y.	June 8, 1887
KAMMERER, JACOB A.	General Agent, The Royal Electric Co.; residence, 87 Jameson Ave., Toronto, Ont.	April 28, 1897
KEEFER, EDWIN S.	Supt. of Electric Light Construction, Western Electric Co., 57 Bethune St., New York City; residence, Elizabeth, N. J.	April 18, 1894
KEILHOLTZ, P. O.	General Manager. United Electric Light and Power Co., and Chief Engineer, United Railways and Electric Co., 330 N. Charles St., Baltimore, Md.	Mar. 21, 1893
KELLER, E. E.	Vice-Prest. and General Manager, Westinghouse Machine Co, Pittsburg, Pa.; residence, Edgewood Park, Pa.	Sept. 20, 1893
KELLER, EDWIN R., *M.E.*	Mechanical and Electrical Engineer, Falkenau Engineering Co., Ltd., 727 Reading Terminal, 4823 Springfield Ave., Philadelphia, Pa.	Mar. 21, 1894
KELLOGG, JAMES W., *M.E.*	Manager Marine Sales, General Electric Co., residence, 10 Front St., Schenectady, N. Y.	June 26, 1891
KELLY, JOHN F.	The Stanley Electric Co., Pittsfield, Mass.	May 16, 1899
KENAN, WM. R. JR.	Sup't Union Carbide Co., Sault Ste. Marie, Mich.	Jan. 20, 1897
KENNEDY, A. P.	Electrical Engineer, Norton Bros., 312 N. 3rd Ave., Maywood, Ill.	Apr. 26, 1899
KER, W. WALLACE	Instructor of Electricity, Hebrew Technical Institute, 36 Stuyvesant St., New York City. Residence, 626 Pavonia Ave., Jersey City, N. J.	Sept. 25, 1895
KING, VINCENT C., Jr.	With V. C. & C. V. King, 517 West St.; residence, 110 East 16th Street, New York.	Aug. 5, 1896
KINSLEY, CARL	C/o. Signal Officer, Governer's Island, New York Harbor.	May 18, 1897
KIRKLAND, JOHN W.	Electrical Engineer, Box, 1905, Johannesberg, S. A. R.	Mar. 21, 1894
KITTLER, DR. ERASMUS	Professor at the Technical High School, Darmstadt, Germany.	Dec. 16, 1896
KLAUDER, RUDOLPH H.	Electrical Engineer, The Electric Storage Battery Co., Philadelphia, Pa.	Aug. 13, 1897
KLINCK, J. HENRY	Box 157 Port Oram, N. J.	Jan. 16, 1895
KNOX, FRANK H.	Engineer, Spartanburg Railway, Gas & Electric Co., Spartanburg S. C.	June 20, 1894

Name.	Address.	Date of Election.
KNOX, GEO. W.	Engineer and Manager, Railway Dep't. Kohler Bros., 1812 Fisher B'ld'g; 866 E. 48th St., residence, 2329 Magnolia Ave., Chicago, Ill.	Nov. 18, 1896
KNOX, S. L. G.	Mechanical Engineer, General Electric Co., Schenectady, N. Y.	Nov. 23, 1898
KREIDLER, W. A.	Editor and Publisher, *Western Electrician*, 510 Marquette Building, Chicago, Ill.	Oct. 4, 1887
LABOUISSE, JOHN PETER *M.E.*	Supply Dep't, Philadelphia Office, General Electric Co., 507 Arch St., residence, 1630 Arch St., Philadelphia, Pa.	Aug. 5, 1896
LAMB, RICHARD	Chief Engineer, Brooklyn Dock and Terminal Co., and the Brigantine Trolley Co, 136 Liberty St.; residence, Waterwitch Park, Highlands, N. J.	Dec. 18, 1895
LAND, FRANK	Sec'y and Treas., I. A. Weston Co., residence, 221 Green St, Syracuse, N. Y.	Sept. 22, 1891
LANMAN, WILLIAM H.	Board of Patent Control, 120 Broadway, New York City.	June 6, 1893
LANPHEAR, BURTON S.	Lock Box 1, Carthage, N. Y.	Jan. 16, 1895
LANSINGH, VAN RENSSELAER	Electrical Engineer, Western Electric Co.; residence, 5407 Woodlawn Ave., Chicago, Ill.	Aug. 23, 1899
LATHAM HARRY MILTON	With American Steel and Wire Co., Worcester, Mass.	Dec. 16, 1896
LAWRENCE, WM. G.	Manager of Light and Power Department, Town of Hudson, Hudson, Mass.	Feb. 28, 1900
LAWRENCE, W. H.	Assistant Superintendent, Second District, Edison Electric Illuminating Co., 49 West 26th St., New York, N. Y.	April 26, 1899
LAYMAN, W. A.	Assistant Manager and Treasurer, Wagner Electric M'f'g. Co., 2017 Locust St. St. Louis, Mo.	Nov. 22, 1899
LEBLANC, CHARLES	Ingenieur en Chef, de la Compagnie Generale de Traction, 24 Boulevard des Capucines, Paris. France.	April 17, 1895
LECLEAR, GIFFORD,	Electrical and Mechanical Engineer, Partner Densmore & Le Clear, 7 Exchange Place Boston, Mass.; residence, Cambridge, Mass.	Oct. 27, 1897
LECONTE, JOSEPH NISBET	Instructor in Electrical Engineering, State University, Berkeley, Cal.	Feb. 27, 1895
LEDOUX, A.R., *M. S.*, *Ph.D.*,	President of Ledoux & Co.(inc.), 99 John St., residence, 39 W. 50th St., New York City.	Dec. 7, 1886
LEE, FRANCIS VALENTINE T.	Engineer, (Pacific Coast Dept.) Stanley Electric M'f'g. Co., 33 New Montgomery St., San Francisco, Cal.	Mar. 23, 1898

Name.	Address.	Date of Election
LEE, JOHN C.	Chemist and Electrician, American Bell Telephone Co., Boston residence; Mountfort St., Longwood, Brookline, Mass.	Mar. 18, 1890
LEITCH, HOWARD WALLACE	Switchboard Regulator. The Edison Elect. Illuminating Co., residence, 373 Madison St., Brooklyn, N. Y.	Nov. 23, 1898
LEMON, CHARLES,	Hon. Sec'y for New Zealand for the Institution of Electrical Engineers, Waerenga Road, Otaki, New Zealand.	Jan. 22, 1896
LETHEULE, PAUL	Electrical Engineer, Commissioned by French Government, 27 Rue de Londres, Paris, France.	May 17, 1898
LEVY, ARTHUR B.	Assistant Engineer, Arc Light Dept., General Electric Co., 810 Lexington Ave., New York City.	Jan. 20, 1891
LEWIS, HENRY FREDERICK WILLIAM,	Redlands, 48 Sydenham Road, Croydon, Surrey, England.	Mar. 5, 1889
LIBBY, SAMUEL BYINGTON	Richmond Borough Equipment Co., 395 Richmond Terrace, New Brighton, N. Y.	Feb. 23, 1898
LILLEY, L. G.	Electrician, The Cincinnati Underwriters' Association S. W. Cor. 3d and Walnut Sts., Cincinnati, O.; residence, Wyoming, O.	June 20, 1894
LINDSAY, ROBERT	General Supt. The Cleveland Elec. Ill. Co., 717 Cuyahoga Building, Cleveland, Ohio.	April 27, 1898
LINDSAY, WM. E.	With Wm. Sellers & Co., 1600 Hamilton St., residence, 1638 Vine St., Philadelphia, Pa.	April 17, 1895
LITTLE, C. W. G.	Engineering Manager, The British Electric Traction Co, Ltd., Donington House, Norfolk St., Strand, W. C., London, Eng.	April 22, 1899
LIVINGSTON, JOHNSTON JR.	The United Engineering and Contracting Co., 13 Park Row; residence, 56 E. 49th St., New York City.	May 17, 1898
LOEWENTHAL, MAX	Associate Editor, *Power*, Pulitzer B'ld'g residence, 161 East 77th St., New York City.	Mar. 23, 1898
LOHMANN, R. W.	R. W. Lohmann & Co., Electrical Contractors, 1387 Madison St., Oakland, Cal	Nov. 23, 1898
LORIMER, GEO. WM.	Sec'y and Treasurer, The American Machine Telephone Co., Ltd., Piqua, O.	Aug. 5, 1896
LORIMER, JAMES HOYT	Electrical Engineer, The American Machine Telephone Co., Ltd., Piqua. O.	Aug. 5, 1896

Name.	Address	Date of Election
LOUIS, OTTO T.	Manager of New York Branch, Queen & Co., Inc.; residence, 340 East 119th St., New York City.	Feb. 23, 1898
LOVEJOY, D. R.	Care C. S. Bradley, 44 Broad St., New York, N. Y	April 28, 1897
LOW, GEORGE P.	Editor and Proprietor, *Journal of Electricity, Power and Gas*, 320 California St., Francisco, Cal.	Jan. 17, 1893
LUNDELL, ROBERT	Electrical Engineer, 527 W. 34th St., residence, 9 W. 68th St., New York City.	Feb. 7, 1890
LUNDIE, JOHN	Consulting Engineer, 52 Broadway, New York City.	Nov. 22, 1899
LUQUER, THATCHER, T. P.	New York Telephone Co., 15 Dey St., residence, Bedford, N.Y.	June 26, 1891
LYFORD, OLIVER S., JR.,	C/o. Siemens & Halske Electric Co. of America, 98 Jackson St., Chicago, Ill.	Apr. 26, 1899
LYMAN, CHESTER WOLCOTT, *M. A.*	Assistant to President International Paper Co., 30 Broad St., residence, University Club, New York, N. Y.	Sept. 19, 1894
LYMAN, JAMES [Life Member.]	Assistant Engineer, Chicago Office, General Electric Co, Monadnock B'ld'g., residence, 13 8 Maple Ave., Chicago, Ill.	Sept. 19, 1894
LYNN, WM. A.	Instructor in Electrical Engineering, University of California, Berkeley, Cal.	Jan. 25, 1899
LYONS, JOSEPH,	Patent Solicitor, with Gustav Bissing 908 G. St., Washington, D. C.	June 24, 1898
MACARTNEY, JOHN F.	Managing Director, Macartney, McElroy & Co, L't'd., 53 Victoria St., London, Eng.	May 16, 1899
MACFADDEN, CARL K.	Consulting Engineer, Geneva, Ind.	Sept. 27, 1892
MACGREGOR, WILLARD H.	General Eastern Agent, Cutler-Hammer. Mfg. Co. of Chicago. 136 Liberty St.; residence, 359 W. 27th St., New York City.	Jan. 20, 1897
MACKIE, C. P.	30 Broad St., New York City; residence, Englewood, N. J.	Mar. 21, 1893
MACLEOD, GEORGE	Superintendent and Engineer, Kentucky and Indiana Bridge Co., 29th and High Sts.; residence, 1913 4th Ave., Louisville, Ky.	Aug. 5, 1896
MACOMBER, IRWIN JOHN	Professor of Electrical Engineering Armour Institute of Technology, residence, 422 34th Street, Chicago, Ill.	Mar. 28, 1900
MAGEE, LOUIS J.	Electrical Engineer, Director, der Union Elektricitats Gesellschaft, Grosse Quer Allee 1., Berlin, Germany.	April 2, 1889
MAGNUS, BENJAMIN	Electrical Engineering Student, Columbia University; residence, 22 E. 111th Street, New York City.	Jan. 24, 1900
MAHONEY, JAMES J.	Engineer General Electric Co., 44 Broad St., residence, 115 W. 47th St., New York City.	May 17, 1898

Name.	Address.	Date of Election.
MAKI, HEIICHIRO	Chief Engineer, Hōshyū Traction Co., Beppu, Oitaken, Japan.	Aug. 5, 1896
MALIA, JAMES P.	Electrician, Armour & Co., 5316 Union Ave., Chicago, Ill.	June 20, 1894
MANSFIELD, R. H. Jr.,	President, Iron Clad Resistance Co., Westfield, N. J.	Sept. 28, 1898
MARSHALL, CLOYD	Designer of Electrical Machinery, Jenney Elec. M'f'g. Co., Indianapolis, Ind.	Apr. 25, 1900
MARTIN, FRANK	Superintendent, Universal Lock Co., Woodbine, N. J., and 56 Liberty St., New York City.	Oct. 21, 1890
MARTIN, JAMES A.	[Address Unknown.]	May 19, 1896
MARTIN JOHN	Agent, Stanley Electric M'fg. Co., 33 New Montgomery St., San Francisco, Cal.	July 27, 1898
MARTIN, T. COMMERFORD	(*Past-President.*) Editor, *The Electrical World and Engineer*, 120 Liberty St., N. Y. City.	April 15, 1884
MASSON, RAYMOND S.	Salesman and Engineer, Westinghouse E. & M. Co., Mills B'ld'g, San Francisco, Cal.	Apr. 26, 1899
MATHER, EUGENE HOLMES	Central Railway and Electric Company, New Britain, Conn.	April 28, 1897
MATTHEWS, CHARLES P.	Associate Professor, Electrical Engineering, Purdue University, residence, Thornell St., Lafayette, Ind.	May 16, 1893
MAXWELL, EUGENE	c/o Snoqualmie Falls Power Co., Seattle, Wash.	Aug. 5, 1896
MAURO, PHILIP	Counsellor at-Law in Patent Causes (Pollock & Mauro), 620 F. St., Washington, D. C.	Dec. 21, 1892
MAYER, MAXWELL M.	Mfr. of Plating Dynamos, 2369 2d Ave., residence 433 East 116th St., New York City.	Feb. 27, 1895
MCCARTER, ROBERT D. JR.	Electrical Engineer, Union Elektricitats Gesellschaft, 16 Hutten St., Berlin N. W. 87, Germany.	May 16, 1899
MCCARTHY, E. D.	McCarthy Bros. & Ford, 45 North Division St.; residence, 382 West Ferry Street, Buffalo, N. Y.	Nov. 18, 1896
MCCLENATHAN, ROBERT	Division Superintendent, Electric Train Bulletin Co., Box 476, Ithaca, N. Y.	May 16, 1899
MCCLUER, CHAS. P.	Assistant General Manager, Richmond Telephone Co., 2804 E. Franklin St., Richmond, Va.	Apr. 22, 1896
MCCLURE, WILLIAM J.	Associated with H. D. Brown, Electrical Engineers and Contractors, residence, 259 West 52nd St., New York City.	Apr. 25, 1900
MCCLURG, W. A	Manager, Electrical Dept., Plainfield Gas and Electric Light Co., 207 Madison Ave., Plainfield, N. J	Dec. 20, 1893
MCELROY, JAMES F.	Consulting Engineer, Consolidated Car Heating Co., 131 Lake Ave., Albany, N. Y.	Nov. 15, 1892
MCKISSICK, A. F.	Engineer, Pelzer Manufacturing Co., Pelzer, S. C.	Feb. 16, 1892

Name.	Address.	Date of Election.
McLain, Ralph Clapp	Assistant Engineer, Rapid Transit Subway Construction Co., 21 Park Row, residence, 170 W. 59th St, New York N. Y.	Aug. 23, 1899
McRae, Austin Lee	Consulting Electrical Engineer, 306 Oriel Bldg, St. Louis, Mo.	May 17, 1892
McVay, H. D.	City Electrician, City of Wichita, Wichita, Kan.	Feb. 28, 1900
Meadows, Harold Gregory	Associate Engineer (Elec.) with Newcomb Carlton, 109 White Building; residence, 238 Elmwood Ave., Buffalo, N. Y.	Sept. 23, 1896
Medina, Frank P.	Electrician, Pacific Postal Telegraph Co., 534 Market St., San Francisco, Cal.	Sept. 19, 1894
Meredith, Wynn	Electrical Engineer, Benjamin, Hunt, and Meredith, 331 Pine St., San Francisco, Cal.	Jan. 17, 1893
Merrill, E. A.	Manager, New York Office, MacIntosh and Seymour, 26 Cortlandt St., New York City.	Sept. 20, 1893
Merrill, Josiah L.	Electrical Engineer, c/o. General Electric Co., 420 W. 4th St., Cincinnati, O.	Sept. 25, 1895
Merz, Chas. H.	The Cork Electric Tramways and Lighting Co. Ltd., Cork; residence, The Quarries, Newcastle-on-Tyne, England.	Sept. 25, 1895.
Meyer, Hans S.	Electrical Engineer, Union Elektricitats Gesellschaft, Huttenstrasse 12, Berlin, Germany	July 27, 1889
Meyer, Julius	Consulting Engineer, Broadway, 55 New York City.	Oct. 25, 1892
Middleton, A. Center	Electrical Tester, General Electric Co., Box 253, Schenectady, N. Y.	May 16, 1899
Miller, Herbert S.	Electrical Engineer, Diehl Mfg. Co.; residence, 1025 E. Jersey St., Elizabeth, N. J.	Mar. 22. 1899
Miller, Kempster B.	Engineer Kellogg Switchboard and Supply Co., Congress and Green St., residence, 6017 Woodlawn Ave., Chicago, Ill.	Sept. 28, 1898
Miller, Wm. C., *M. S.*	Electrical Engineer, 3 South Hawk St., Albany, N. Y.	Oct. 21, 1890
Misaki, Seizo	Chief Engineer and Superintendent Hanshin Elec. R. R. Co., Front Sannomiyo Station, Kobe, Japan.	Dec. 27, 1899
Mitchell, Sidney Z.	Manager, Portland Office, General Electric Co., Worcester Building, Portland, Ore.	Nov. 12, 1889
Molé, Harvey Edward	with J. G. White & Co., 29 Broadway, New York City.	Nov. 30, 1897

Name.	Address.	Date of Election
MONTAGU, RALPH LECHMERE	Continental Gold Dredging Co., Oroville, Cal.	Feb. 26, 1896
MOODY, VIRGINIUS DANIEL	Senior Student, Cornell University, residence, 215 Dryden Road, Ithaca, N. Y.	Dec. 27, 1899
MORA, MARIANO LUIS	General Electric Co., 44 Broad St., New York City.	Mar. 20, 1895
MORDEY, WM. MORRIS	Consulting Electrician, 82 Victoria St., Grosvenor Mansions. Westminster, London, Eng	Sept. 22, 1891
MOREHEAD, J. M.	Engineer, Union Carbide Co, 157 Michigan Ave., Chicago, Ill.	Mar. 28, 1900
MOREHOUSE, H. H.	Morehouse and Morrill. General Electric Installation and Contracting Work Apartado No 44, Quezaltenango, Guatemala, C. A	Feb. 21, 1894
MORGAN, CHAS. H.	4th Ass't Examiner, U. S. Patent Office, residence, 43 R St., N. W. Washington, D. C.	Aug. 5, 1896
MORGAN, JACQUE L.	City Electrician, City Hall, residence, 1702 Locust St., Kansas City, Mo.	Jan. 26, 1898
MORLEY, EDGAR L.	Sup't Hatzel & Buehler, 114 5th Ave., New York City.	Sept. 25, 1895
MORRISON, J. FRANK	Manager, The Northern Electric Co. 15 South St., Baltimore, Md.	April 15, 1884
MORTIMER, JAMES D.	Student, Electrical Engineering, University of California, Mechanics' Building, Berkeley, Cala.	Mar. 28, 1900
MORTLAND, JAMES A.	Sergeant 12th Co., U. S. V., Signal Corps, Official Photographer, 3d Army Corps, Montezuma, Iowa.	Feb. 23, 1898
MORTON, HENRY, *Ph.D.*	President of Stevens Institute of Technology, Hoboken, N. J.	May 24, 1887
MOSES, OTTO A.	Electrician, 1037 Fifth Ave., New York City.	May 17, 1887
MOSES, PERCIVAL ROBERT, *E.E.*	Electrical Engineer, 35 Nassau St.: residence, 46 West 97th St., New York City.	Dec. 19, 1894
MOSSCROP, WM. A., *M.E*	Electrical Engineer, 47 Brevoort Place, Brooklyn, N. Y.	May 7, 1889
MULLIN, E. H.	General Electric Co., 44 Broad St., residence, 188 Columbus Ave., New York, N. Y.	May 16, 1899
MUNNS, CHAS. K.	Electrical Engineer, Corning, Iowa.	Nov. 21, 1894
MURPHY, JOHN MCL.	Electrical Engineer, Safety Third Rail Electric Co., 40 Wall St., New York, N. Y.	Oct. 26, 1898
MUSCHENHEIM, FRED'K A.	Electrical Engineer, Western Electric Co., 57 Bethune St., residence, 41 W. 31st St., N. Y. City.	April 27, 1898
NAMBA, M.	Professor of Electrical Engineering, University of Kioto, Kioto, Japan.	Apr. 26, 1899

Name.	Address.	Date of Election.
NAPHTALY, SAM L.	Manager and General Superintendent, The Central Light and Power Co., Room 500, Parrott Building, residence, 1404 Broadway, San Francisco, Cal.	Aug. 23, 1899
NEILSON, JOHN	Larchmont, N. Y.	May 18, 1897
NEURATH, MORRIS M.	Consulting Engineer, 1444 Monadnock Block, Chicago, Ill.	Feb. 28, 1900
NEWBURY, F. J.	Manager Insulated Wire Department, John A. Roebling's Sons Co., Trenton, N. J.	Sept. 23, 1896
NILES, HARRY B.	Electrical Engineer, Ferrocarrillos del Distrito American Club, Mexico City.	Jan. 24, 1900
NIMIS, ALBERT A.	Electrical Contractor, Nimis & Nimis, 59 East 5th Street, St. Paul, Min. and 1221 Lexington Ave., N. Y. City.	Aug. 13, 1897
NOCK, GEO. W.	Chief Engineer, in charge of Steam and Electric Plant Westinghouse Elect. and Mfg. Co., Pittsburg, Pa.	Aug. 5, 1896
NOXON, C. PER LEE	Manufacturer, High-Frequency X-Ray Apparatus, Dynamos and Motors, 500 East Water Street, Syracuse, N. Y.	Oct. 17, 1894
NUNN, RICHARD J., *M. D.*	Physician, 5 York St. East, Savannah, Ga.	July 12, 1887
NYHAN, J. T.	Superintendent and Electrician, Macon and Indian Spring Electric Railway, Macon, Ga.	Feb. 27, 1895
OCKERSHAUSEN, H. A.	Electrical Engineer, 65 Madison Ave., Jersey City, N. J.	Sept. 6, 1887
OFFINGER, MARTIN HENRY	Head of Electro-Mechanical Dept., Buffalo Commercial & Electro Mechanical Institute, residence, 304 Pine St., Buffalo, N. Y.	Mar. 28, 1900
OI, SAITARO	Chief Engineer to the Bureau of Telegraphs The Ministry of Communications, 16 Kamitomisakacho, Koishikawa, Tokyo, Japan.	Dec. 28, 1898
OLAN, THEODOR, J. W.	[Address unknown.]	May 16, 1893
OLIVETTI, CAMILLO	Ingegnere Industriale, Ivrea, Italy.	Oct. 17, 1894
ORMSBEE, ALEX. F.	Electrical Engineer, with N. Y. and N. J. Telephone Co., 81 Willoughby St.; residence, 183 Joralemon St., Brooklyn, N. Y.	June 27, 1895
OSBORNE, LOYALL ALLEN	Manager of Works, Westinghouse Electric and Mfg. Co., Pittsburg, Pa.	Oct. 18, 1893
OSTERBERG, MAX, *E.E.*, *A.M.*	Consulting Engineer, and Electrical Expert, Bowling Green Building, New York City.	Jan. 17, 1894
O'SULLIVAN, M. J.	Superintendent, Electric Light, B. & O. R. R. Co., 202 Hazelwood Ave., Pittsburg, Pa.	Mar. 20, 1895

Name.	Address.	Date of Election.
OTTEN, DR. JAN D.	Director, Batavia Electrische Tram-Maatschappij, Van Baerlstraat 80, Amsterdam, Holland.	Nov. 18, 1890
PAGE, A. D.	Assistant Manager, General Electric Co. Lamp Works, Harrison, N. J.	Jan. 19, 1892
PARKER, HERSCHEL C.	Tutor in Physics, Columbia University, 21 Fort Green Pl., Brooklyn, N. Y.	April 19, 1892
PARMLY C. HOWARD, *S.M.*, *E.E.*	College of the City of New York, 17 Lexington Ave.; residence, 514 W. 114th St., New York City.	Feb. 21, 1893
PARRY, EVAN	Engineer, c/o. H. F. Parshall, 8 Princes St, Bank; residence, Sunningdale, Fitzgerald Ave., Mortlake, London, Eng.	Sept. 25, 1895
PARSELL, HENRY V. A. JR.	Electrical and Mechanical Designing and Experimental Work, 129 W. 31st St, residence, 31 E. 21st St., New York City.	Nov. 12, 1889
PATTON, PRICE I.	The Bartram, 33d and Chestnut St., Philadelphia, Pa.	Mar. 20, 1895
PEARSON, FRED'K J.	Supt. of Construction, Western Electric Co., 1510 Howard St., Omaha, Neb.	July 27, 1898
PECK, EDWARD F.	187 Montague St.; residence, 700 Nostrand Ave., Brooklyn, N. Y.	May 20, 1890
PECK, JOHN S.	Electrical Designer, The Westinghouse E. & M. Co., Pittsburg, Pa.	Apr. 26, 1899
PECKHAM, W. C.	Prof. of Physics, Adelphi College, Brooklyn; residence, 406 Classon Ave., Brooklyn, N. Y.	Nov. 30, 1897
PEIRCE, ARTHUR W. K.	Consulting Electrical Engineer to the Consolidated Gold Fields of South Africa, Ltd., Germiston S. A. R.	June 27, 1895
PENDELL, CHAS. WILLIAM	Post-Graduate Student, Mass. Institute of Technology, 207 W. Newton St., Boston, Mass., residence, Cleburne, Texas.	Nov. 22 1899
PERKINS, FRANK C.	Electrical Engineer, 126 Erie Co. Bank, 655 Prospect Ave., Buffalo, N. Y.	Oct. 21, 1890
PETTY, WALTER M.	Superintendent Fire Alarm Telegraph, Rutherford, N. J.	May 16, 1893
PFEIFFER, ALOIS J. J.	Engineer, Thomas-Houston Co., 5 Piazza Castello Milano, Italy.	Jan. 24, 1900
PFUND, RICHARD	601 W. 169th St., New York City.	April 18, 1893
PHELPS, WM. J.	Manager, Phelps Manufacturing Co., Electrical Specialties, Elmwood, Ill.	Mar. 25, 1896
PHILBRICK, B. W.	Electrical Engineer for J. J. Astor, Rhinecliff, N. Y.	May 15, 1894
PHILLIPS, EUGENE F.	President, American Electrical Works, Phillipsdale, R. I.	July 13, 1889
PHILLIPS, LEO A.	Superintendent, New York and Queens Light and Power Co., 66 Lawrence St., Flushing, N. Y.	Mar. 21, 1894

Name.	Address.	Date of Election.
PILLSBURY, CHAS. L.	Sup't Minneapolis International Electric Co., Edison Building, Sec'y State Board of Electricity, Minneapolis, Minn.	Aug. 13, 1897
PINKERTON, ANDREW	Electrical Engineer, The Apollo Iron and Steel Co., Vandergrift Pa.	Sept. 25, 1895
PLUMB, CHARLES	Proprietor and Electrician, The Chas. Plumb Electrical Works, 70 West Swan St., Buffalo, N. Y.	June 20, 1894
POMEROY, WILLIAM D.	Electrician, Akron Electric Mfg. Co., 1106 So Main St., Akron, O.	Mar. 22, 1899
POOLE, CECIL P.	Editor *American Electrician*, 120 Liberty St., residence, 163 W. 84th St., New York City.	Jan. 3, 1888
POOLE, CHARLES OSCAR	Superintendent Electrical Dept., Standard Electric Co., of California, Crocker Bldg.; residence, 452 Bryant St, San Francisco, Cal.	Jan. 24, 1900
POPE, HENRY W.	Acting General Manager, Bell Telephone Co., of Buffalo; residence, 455 Richmond Ave, Buffalo, N.Y.	Mar. 23, 1898
POPE, RALPH WAINWRIGHT	Secretary to the American Institute of Electrical Engineers, 26 Cortlandt St., (Telephone, 2199 Cortlandt), New York City; residence, 570 Cherry St., Elizabeth, N. J.	June 2, 1885
PORTER, H. HOBART, JR.	Sanderson & Porter, 31 Nassau St., New York; residence, Lawrence, L.I.	Mar. 25, 1896
POWELL, PERCY HOWARD	*M. E.*, Bridgeport Brass Co.; residence, 530 State St., Bridgeport, Conn.	Sept. 25, 1895
POWELSON, WILFRED VAN NEST,	Government Inspector, Electrical Appliances. General Electrical Co, Schenectady, N. Y.; Lieutenant U. S. Navy.	Jan. 24, 1900
PRICE, CHAS. W.	Editor the *Electrical Review*, 41 Park Row, New York City; residence, 223 Garfield Place, Brooklyn, N. Y.	Sept 19, 1894
PRICE, EDGAR F.	Works Manager, Union Carbide Co., residence, 625 Buffalo Ave., Niagara Falls, N. Y.	June 27, 1895
PRINCE, J. LLOYD	Edison Illuminating Co., New York City; residence, 868 Flatbush Ave., (Flatbush Station), Brooklyn, N. Y.	Feb. 27, 1895
PRIVAT, LOUIS	Electrician, Cicero Water, Gas and Electric Light Co., Oak Park, Ill.	Dec. 19, 1894
PROCTOR, THOS. L.	Electrical Engineer, 39 Cortlandt St., New York, residence, Newtown, L. I., N. Y.	April 18, 1894
PROSSER, HERMAN A.	Electrician, c/o Baltimore Copper Works., Keyser Bldg.; Baltimore, Md.	Jan. 26, 1898
PUPIN, DR. MICHAEL I.	Adjunct Professor in Mechanics, Columbia University; residence, 280 North Broadway, Yonkers, N. Y.	Mar. 18, 1890

Name.	Address.	Date of Election
RAMSEY, HARRY NATHAN	Electrician Columbia & Electric Vehicle Co., Hartford, Ct., residence, 311 Healy St., Olean, N. Y.	May 16, 1899
RANDALL, JOHN E.	Columbia Incandescent Lamp Co., 1912 Olive St., St. Louis, Mo.	May 7, 1889
RANDOLPH, L. S.	Professor of Mechanical Engineering, Blacksburg, Va.	Feb. 21, 1893
RATHENAU, ERICH	Electrical Engineer, Allg. Electricitats Gesellschaft, Berlin, Germany.	Nov. 20, 1895
RAUB, CHAS. B.	Electrical Engineer, care U. S. Engineer's Office Newport, R. I.	Nov. 22, 1899
RAY, WILLIAM D.	Woods Motor Vehicle Co., 245 Wabash Ave., Chicago, Ill.	Sept. 27, 1892
READ, ROBERT H.	Patent Attorney, General Electric Co., Schenectady, N. Y.	Jan. 19, 1892
REED, CHAS. J.	Electrician, 3313 N. 16th St., Philadelphia, Pa.	Mar. 5, 1889
REED, HARRY D.	Superint'd't Bishop Gutta Percha Co., 420 East 25th St., New York City; residence, 88 North 9th St., Newark, N. J.	Sept. 19, 1894
REED, HENRY A.	Secretary and Manager, Bishop Gutta-Percha Co., 422 East 25th St., New York City; residence, 88 North 9th St., Newark, N. J.	June 4, 1889
REED, WALTER WILSON	Electrical Engineer in charge of the electrical work of new plant Citizen Electric Light and Power Co., Houston, Texas. With General Electric Co., Schenectady, N.Y.	Apr. 26, 1899
REICHMANN, FRITZ	Ryerson Physical Laboratory, University of Chicago, Chicago, Ill.	Mar. 23, 1898
REID, EDWIN S.	General Sup't of Construction, National Conduit and Cable Co, 17 Times Building; residence, 112 Madison Ave., New York City	Feb. 26, 1896
REILLY, JOHN C.	General Supt., N. Y. & N. J. Tel. Co., 16 Smith St., Brooklyn, N. Y.	April 15, 1884
RENNARD, JOHN CLIFFORD,	*A. B. E. E.* Consulting and Supervising Electrical Engineer, 15 Dey St., New York City.	Jan. 16, 1895
RENSTROM, FRANS OSCAR	Superintendent, The Regla Power Co., Apartado 95, Pachuca, Mexico.	Feb. 28, 1900
REQUIER, A. MARCEL	Electrical Engineer, Westinghouse Electric Co., (L't'd.) 32 Victoria St., London, S. W. Eng.	Dec. 20, 1893
RICE, ARTHUR L.	Professor of Steam and Electrical Engineering, Pratt Institute, residence, 114 Cambridge Place, Brooklyn, N. Y.	Oct. 21, 1896
RICH, FRANCIS ARTHUR	Manager, Woodstock G. M. Co., Karangahake, Auckland, New Zealand.	Jan. 20, 1897
RICHARDS, CHAS. W.	C. W. Richards & Co., 178 Devonshire St, Boston; residence, Needham, Mass.	Sept. 23, 1896

Name.	Address.	Date of Election.
RICHEY, ALBERT S.	Electrician, Union Traction Co., of Indiana, 215 W. 9th St., Anderson, Ind.	May 18, 1897
RIDEOUT, ALEXANDER C.	*LL. D.*, Consulting Electrical and Mechanical Engineer, Rideout & Gage, 101 Randolph St., Chicago, Ill.	Aug. 5, 1896
RIPLEY, WM. HOWE	Ripley & Arendt, 24 Murray St.; residence, 17 W. 123d St., New York City.	Feb. 17, 1897
ROBERSON, OLIVER R.	Electrician, Western Union Telegraph Co., 195 Broadway, P O. Box 856, New York City.	Dec. 20, 1893
ROBERTS, ALLEN DAVIDSON	Electric Inspector, City Council, Kingston, Jamaica.	Nov. 22, 1899
ROBINSON, ALMON	Webster Road, P. O. Box 943, Lewiston, Me.	Sept. 6, 1887
ROBINSON, DWIGHT PARKER	Assistant General Manager, The Seattle Electric Co., 815 2nd Ave., Seattle, Wash.	Sept. 25, 1895
ROBINSON, FRANCIS GEORGE	With Metropolitan Street Railway Co.; residence, Hotel Richelieu, 114th St. & Fifth Ave., New York City.	Nov. 21, 1894
ROBINSON, GEO. P.	Ass't Supt L. D. Service, The Wisconsin Telephone Co., 498 Milwaukee St., Milwaukee Wis.	May 16, 1899
ROEBLING, FERDINAND W.	Manufacturer of Electrical Wires and Cables, Trenton, N. J.	June 8, 1887
ROLLER, FRANK W. *M.E.*	Electrical Engineer, Machado & Roller, Electrical Machinery, 203 Broadway, N. Y.; residence, Roselle, N. J.	May 21, 1895
ROPER, DENNEY W.	Electrical Supt. 19th and Gratiot St., Mo., residence, Alton, Ill.	June 6, 1893
ROSEBRUGH, THOMAS REEVE	Lecturer in Electrical Engineering, School of Practical Science, Toronto, Ont.	June 26, 1891
ROSENBAUM, WM. A.	Electrical Expert and Patent Solicitor, 177 Times Building, New York City.	Jan. 3, 1889
ROSENBERG, E. M., *M. E.*	Residence, 138 W. 85th St., New York City.	Oct. 21, 1890
ROSENBUSCH, GILBERT	Engineer, Sprague Electric Co., Bloomfield; residence, South Orange, N. J.	Sept. 28, 1898
ROSS, TAYLOR WILLIAM	Second Assistant Engineer, U. S. Revenue Cutter Service, Revenue Cutter "Onondaga," Philadelphia, Pa.	Mar. 25, 1896
ROWLAND, ARTHUR JOHN	Professor of Electrical Engineering, Drexel Institute; residence, 4510 Osage Ave., Philadelphia, Pa.	Sept. 19, 1894
ROWLAND, HENRY A.	Professor of Physics, Johns Hopkins University, Baltimore, Md.	Mar. 21, 1894
RUSHMORE, DAVID B.	Ass't Electrician Stanley Elec. and M'f'g Co., residence, 202 South St., Pittsfield, Mass.	Sept. 25, 1895

Name.	Address.	Date of Election.
RUSHMORE, SAMUEL W.	Proprietor, Rushmore Dynamo Works. 24 Morris St., Jersey City, N. J.	Mar. 28, 1900
RUSSELL, H. A.	Sales Agent, General Electric Co., residence, 302 Laurel St., San Francisco, Cala.	Nov. 22, 1899
RUTHERFORD, WALTER	Manager Electric Traction Dep't, Dick Kerr & Co., Ltd., 110 Cannon St., London E. C., England.	Sept. 22, 1891
RYERSON, WM. NEWTON	Switchboard Attendant, Metropolitan Street Railway Co.; residence, 332 West 56th St., New York.	Aug. 23, 1899
SAGE, HENRY JUDSON	Sage & Co., Electrical Engineers, Rochester, Pa.	Dec. 20, 1893
SAHULKA, DR. JOHANN	Docent of Electrotechnics, Technische Hochschule, Vienna, Austria.	Dec. 20, 1893
SANBORN, FRANCIS N.	29 Wall St., New York City.	Nov. 24, 1891
SANDERSON, EDWIN N.	Of Sanderson & Porter, Engineers and Contractors, 31 Nassau St., New York City.	Oct. 17, 1894
SARGENT, HOWARD R.	Electrical Engineer, General Electric Co.; residence, 17 University Place, Schenectady, N. Y.	Mar. 25, 1896
SATHERBERG, CARL HUGO	Chief Engineer, The Midvale Steel Co., Nicetown, Phila., Pa.; residence 1752 N. 26th St., Philadelphia, Pa.	Aug. 5, 1896
SAXELBY, FREDERICK	Electrical Engineer, 15 Whittlesey Ave., East Orange, N. J.	June 5, 1888
SCHLOSSER, FRED. G.	Superintendent of Electric Dept., Laclede Gas Light Co., 411 N. 11th St. Louis, Mo.	Sept. 22, 1891
SCHOOLFIELD, FRANK ROBERT	Draughtsman, The United Railway and Electric Co., 15 South St.; residence, 738 W. Fayette St., Baltimore, Md.	May 16, 1899
SCHREITER, HEINR. *C. E.*	Counsellor and Attorney, 20 Nassau St., New York City.	Jan. 17, 1893
SCHUM, CHAS. H.	Electrical Engineer, F. A. La Roche & Co., 216 Third Ave., New York City.	Feb. 23, 1898
SCHURIG, EDWARD F.	City Electrician, The City of Omaha, 306 City Hall, Omaha, Neb.	Apr. 26, 1899
SCHIAFFINO, MARIANO L.	Chief Electrician, Compania de Luz Electrica, Guadala jara, Mexico.	Feb. 28, 1900
SCHWAB, MARTIN C.	Electrical Engineer, with Northern Electric Co., 15 South St.; residence, 1729 Madison Ave., Baltimore, Md.	Nov. 18, 1896
SCHWABE, WALTER P.	Superintendent Electrical Dept. Rutherford District, The Gas and Electric Co., of Bergen County, Rutherford, N. J., residence, Carlstadt, N. J.	May 19, 1896

Name.	Address.	Date of Election.
SCHWEDTMANN, FERDINAND	General Sup't Wagner Electric M'f'g Co., 2017 Locust St., St. Louis, Mo.	Nov. 22, 1899
SCHWEITZER, EDMUND OSCAR,	Electrical Inspector, Chicago Edison Co, 139 Adams St.; residence, 1906 Oakdale Ave., Chicago, Ill.	Feb. 15, 1899
SCIDMORE, FRANK L.	With N. Y. C. & H. R. R. R. Co., office of A. F. A.; residence, 21 Highland Ave., Yonkers, N. Y.	Dec. 18, 1895
SCOTT, WM. M.	Electrical Engineer. The Cutter Electrical and Mfg. Co., 1112 Sansom St., Philadelphia, Pa.; residence, 108 West Johnson St, Germantown, Pa.	June 23, 1897
SCUDDER, HEWLETT, JR.,	Assistant to Prof. Henry M. Howe; residence, 21 East 22d St., New York City.	Nov. 22, 1899
SEARING, LEWIS	Consulting, Mechanical, and Electrical Engineer, Denver Engineering Works, Denver, Col.	April 3, 1888
SEARLES, A. L.	Electrical Engineer, Fort Wayne Electric Works, Marquette Building, Chicago, Ill.	April 18, 1894
SEDGWICK, C. E.	Manager, The Hilo Electric Light Co. Ltd., Hilo, H. I.	Feb. 23, 1898
SEE, A. B.	A. B. See Manufacturing Co., 116 Front St.; residence, 107 East 19th St, (Flatbush), Brooklyn, N. Y.	Jan. 17, 1893
SEITZINGER, HARRY M.	Consulting and Constructing Engineer, 6 Northampton St., Wilkes-Barre, Pa.	Sept. 20, 1893
SELDEN, R. L. JR.,	Deep River, Conn.	Jan. 24, 1900
SERRELL, LEMUEL WM.	Mechanical and Electrical Engineer, 99 Cedar St., New York City; residence, Plainfield, N. J.	Nov. 1, 1887
SERVA, A. A.	With Fort Wayne Electric Corporation, 150 Devonshire St., Boston, Mass.	Dec. 20, 1893
SHAFFNER, S. C.	Supt. and Electrician. Electric Lighting Co. of Mobile, Box, 234, Mobile, Ala.	Aug. 13, 1897
SHARPE, E. C.	John A. Roebling's Sons' Co., 25 Tremont St., San Francisco, Cal.	Feb. 26, 1896
SHAW, AUBREY NORMAN	Draughtsman, A B. See M'f'g Co., residence, 298 Carlton Ave., Brooklyn, N. Y.	Mar. 28, 1900
SHAW, HOWARD BURTON	Professor Electrical Engineering, Missouri State University, Columbia, Mo.	April 28, 1897
SHEARER, J. HARRY	Electrical Engineer, National Electric Light Co., Apartado, 639 Mexico City, Mexico.	Jan. 24, 1900
SHEPARD, ROBERTO R.	Erecting Engineer, Mexican General Electric Co., Apartado 403, Mexico City, Mexico.	Jan. 24, 1900

Name.	Address.	Date of Election.
SHOCK, THOS. A. W.	Gen'l Sup't Portland General Electric Co., Portland, Or.	Mar. 20, 1895
SIMPSON, ALEXANDER B.	Electrical Engineer, 54 Maiden Lane, N. Y. City.	May 21, 1891
SIMPSON, J. MANLEY	Assistant to General Superintendent, Northwestern Grass Twine Co., P. O. Box 2513, St Paul, Minn.	Jan. 25, 1899
SISE, CHARLES F.	President, Bell Telephone Co., of Canada, P. O. Box 1918, Montreal, Canada.	June 8, 1887
SKINNER, CHARLES EDWARD	Electrical Engineer, Westinghouse E. & M. Co.; residence, 424 Franklin Ave., Pittsburg, Pa.	Apr. 26, 1899
SKIRROW, JOHN F.	Ass't Manager, Postal Telegraph Cable Co., New York City; residence, 183 N. 19th St., East Orange, N. J.	Sept. 25, 1895
SLADE, ARTHUR J., *Ph.D.*	Engineer, 289 4th Ave.; residence, 62 East 66th St., New York City.	Sept. 19, 1894
SLATER, FREDERICK R.	Asst. Electrical Engineer, Manhattan Rway., 32 Park Place, New York; residence, 153 Warburton Ave., Yonkers, N. Y.	Oct. 17, 1894
SMITH, J. BRODIE	Supt. and Electrician, Manchester Electric Light Co., 142 Merrimack St., Manchester, N. H.	Mar. 21, 1894
SMITH, J. ELLIOT	Superintendent Fire Alarm Telegraph, 122 W. 73d St., New York City.	April 15, 1884
SMITH, OBERLIN	President and Mechanical Engineer, Ferracute Machine Co., Lochwold, Bridgeton, N. J.	May 19, 1891
SMITH, T. JARRARD	Manufacturers and Inventors' Electric Co., 96 Fulton St., Tel. 838 John, New York City; residence, Roselle, N. J.	April 19, 1892
SMITH, WALTER EUGENE	Electrician, The United Electric Improvement Co., 19th and Allegheny Ave., residence, 2010 Ontario St., Philadelphia, Pa.	Feb. 28, 1900
SMITH, WM. LINCOLN	Instructor of Electrical Engineering. Mass. Inst. of Technology, Boston, Mass.; P. O. Box 416, Concord, Mass.	July 18, 1899
SOWERS, DAVID W.	Sup't Buffalo Branch, New York Electric Vehicle Transportation Co., 240 W. Utica, St., residence, 67 W. North St., Buffalo N. Y.	July 18, 1899
SPEED, BUCKNER	Assistant Engineer, Southern Pacific R. R, Tucson, Arizona.	Apr. 22, 1895
SPENCER, PAUL	Inspector of Electric Plants, United Gas Improvement Co., Broad and Arch Sts, Philadelphia, Pa.	Nov. 30, 1897

Name.	Address.	Date of Election.
SPENCER, THEODORE	With Bell Telephone Co., 406 Market St., Philadelphia, Pa.	Mar. 21, 1893
SPERLING, R. H.	Assistant Engineer, British Columbia Electric Railway Co., Ltd., Victoria, B. C.	Nov. 23, 1898
SQUIER, GEORGE O., *Ph.D.*	1st Lieut., 3d Artillery, Chief Signal Office, War Department, Washington, D. C.	May 19, 1891
STADELMAN, WM. A.	Agent, Elwell-Parker Co., 26 Cortlandt St., New York City.	Feb. 7, 1890
STAHL, TH.	Mining Engineer for Messrs. Schneider & Co., Grenoble, France.	Nov. 15, 1892
STAKES, D. FRANKLIN	Electrical Expert and Salesman, c/o. Siemens–Halske Electric Co., of America, 1500 Land Title Bldg. Philadelphia, Pa.	Jan. 20, 1897
STANTON, CHAS. H.	With C. H. & H. Stanton Electrical Contractors, 1517 Walnut St.; residence, 134 S. 3d St., Philadelphia, Pa.	Mar. 20, 1895
STEWART, JOHN BRUCE	Superintendent, Electric Plant, Virginia Hot Springs Co., Hot Springs, Va.	Aug. 23, 1899
STEVENS, J. FRANKLIN	President Keystone Electrical Instrument Co., 9th St. and Montgomery Ave.; Philadelphia, Pa.	Sept. 19, 1894
STEWART, ROBERT STUART	Westinghouse Electric and Mfg., Co., 440 Jefferson Ave., Detroit, Michigan.	Dec. 20, 1896
STEWART, W. M.	District Inspector, New York Telephone Co., 30 Gold St., New York City.	Mar. 25, 1896
STINE, WILBUR M.	Professor of Engineering, Swarthmore College, Swarthmore, Pa.	May 15, 1894
STOCKBRIDGE, GEO. H. [Life Member.]	Patent Attorney, 120 Broadway; residence, 2514 11th Ave, near 187th St., New York City.	May 24, 1887
STONE, CHARLES A.	With Firm of Stone & Webster, 4 P. O. Sq., Boston, Mass.	May 19, 1891
STONE, JOSEPH P.	Electrical Engineer, Bailey, Walker, & Co., Buenos Aires, A. R.	Dec. 18, 1895
STORER, NORMAN W.	Electrical Engineer, Westinghouse Electric and Mfg. Co., Pittsburg; residence, Edgewood, Park, Pa.	Dec. 18, 1895
STOUT, JOSEPH SUYDAM, JR.,	Inspector, Edison Electric Illuminating Co.; 55 Duane St., residence, 35 East 67th St., New York City.	Nov. 22, 1899
STRAUS, THEODORE E.	Electrical Engineer, 13 W. Pratt St., residence, 1213 Linden Avenue, Baltimore, Md.	Nov. 18, 1896
STRAUSS, HERMAN A.	Electrical Engineer, Electrical Construction Dept. Manhattan Railway Co., residence, 111 E. 61st St, New York City.	Oct. 17, 1894
STURDEVANT, CHAS. RALPH	Assistant Professor of Electrical Engineering, Kentucky State College, Lexington, Ky.	May 16, 1899

Name.	Address.	Date of Election.
STURTEVANT, CHARLES L.	Patent Attorney, Atlantic Building, Washington, D. C.	Dec. 20, 1893
STUTZ, CHAS. C.	Chief Draughtsman, Sprague Electric Co., residence, 7 West 92nd Street New York City.	Mar. 28, 1900
SUMMERS, LELAND L.	Electrical Engineer, 441 The Rookery, Chicago, Ill.	Feb. 16, 1892
SWANN, JOHN JOSEPH	The Ingersoll-Sergeant Drill Co., 26 Cortlandt St., residence, 12 East 47th Street, New York.	Jan. 26, 1898
SWENSON, BERNARD VICTOR	Assistant Professor of Electrical Engineering, University of Wisconsin, 404 W. Mifflin St., Madison, Wis.	Feb. 27, 1895
SWEET, HENRY N.	2nd Vice-President, residence, 449 Washington St., Bridgeport, Conn.	May 20, 1890
SWOOPE, C. WALTON	Instructor, Electrical Engineering, Spring Garden Institute; residence, 12 North 38th St, Philadelphia, Pa.	Jan. 26, 1898
SWOPE, GERARD	Electrical Engineer, Western Electric Co., Security B'ld'g, St. Louis, Mo.	Apr. 26, 1899
SYKES, HENRY H.	Chief Engineer, Bell Telephone Co., of Mo., Telephone Bldg., St. Louis, Mo.	Oct. 18, 1893
TACHIHARA, JIN	Electrical Engineer, Mining Dep't, Mitsu Bishi Co., Tokyo, Japan.	Jan. 26, 1898
TAIT, FRANK M.	Superintendent, The Somerset Lighting Co., Somerville, N. J.	Sept. 19, 1894
TAPLEY, WALTER H.	Electrician in Government Printing Office, care of Public Printer, Washington, D. C.	Oct. 25, 1892
TAYLOR, IRVING A.	c/o. Albert B. Herrick, 120 Liberty St. New York City.	May 17, 1898
TAYLOR, JEREMY F.	Electrician, Detroit Copper Company, Morenci, Arizona.	Dec. 27, 1899
TEMPLE, WILLIAM CHASE	Consulting Engineer, Bank of Commerce Bldg., residence, 1090 Shady Ave., Pittsburg, Pa.	May 3, 1887
TESLA, NIKOLA	Electrical Engineer and Inventor, 46 E. Houston St., New York City.	June 5, 1888
THAYER, GEORGE LANGSTAFF, *M. E.*	Electrical Engineer, Oregon Short Line R. R. Co., c/o G. H. Thayer, 22, 5th Ave., Chicago, Ill.	Aug. 5, 1896
THOMAS, ROBERT MCKEAN, *E. E.*	Member of the firm of Thomas & Betts, 141 Broadway; residence, 135 Madison Ave., New York City.	April 22, 1896
THOMPSON, ALFRED J.	Manager, Electrical Dep't. Krajewski-Pesant Company, O'Reilly 15, Havana, Cuba.	Jan. 25, 1899
THOMPSON, JOHN WEST	c/o El Portezuelo Light & Power Co., Puebla, Estado de Puebla, Mexico.	Sept. 28, 1898
THOMPSON, MILTON T.	Constructing Engineer, Mexican General Electric Co., Apartado 403, Mexico City, Mexico.	Jan. 24, 1900

Name.	Address.	Date of Election.
THOMPSON, SILVANUS P.	Morland, Chislett Road, West Hampstead, London, N. W., England.	Oct. 27, 1897
THOMPSON, THOS. PERRIN	Master Electrician, Construction Dept. Norfolk Navy Yard, Portsmouth, Va.	Jan. 25, 1899
THORDARSON, CHESTER H.	Manufacturing Electrican, 43 Franklin St.; residence, 6415 Lexington Ave., Chicago, Ill.	Dec. 18, 1895
THURBER, HOWARD F.	General Superintendent, New York Telephone Co., 18 Cortlandt Street, New York City; residence, 49 Sidney Place, Brooklyn, N. Y.	Mar. 25, 1896
TOERRING, C. J.	C. J. Toerring Co., 1035 Ridge Ave., Philadelphia, Pa.	April 18, 1894
TOLMAN, CLARENCE M,	Electrical Engineer, c/o Edward G. Stoiber, Silverton, Col.	April 27, 1898
TORCHIO, PHILIPPO	Engineering Dep't, The Edison Elec. Illuminating Co., 53 Duane Street, New York City.	June 27, 1895
TOWER, GEORGE A.	V. P. Tower, Binford Electric and M'f'g. Co., 704 E. Main St., residence, 1414 Grove Ave., Richmond, Va.	May 15, 1894
TOWNSEND, HENRY C.	Attorney and Expert in Electrical Cases, 141 Broadway, New York City.	July 10, 1888
TOWNSEND, FITZHUGH	Electrical Engineer, 116th Street and Amsterdam Ave.; residence, 173 Fifth Ave., New York City.	Jan. 20, 1897
TREADWELL, AUGUSTUS, JR.	*E. E.*, 100 Broadway, New York City; residence, 488 3d St., Brooklyn, N. Y.	Feb. 21, 1894.
TRIPIER, HENRI	Counsel and Technical Engineer, of the Compagnie des Transports Electriques de l'Exposition Paris, France; residence, 17 rue Caralloti, Paris, France.	Sept. 28, 1898
TROTT, A. H. HARDY [Life Member.]	Beer, near Axminster, Devonshire, Eng.	Jan. 20, 1891
TRUESDELL, ARTHUR E.	Engineer, Norfolk Railway and Light Co., 82 Plume St., Norfolk, Va.	Feb. 15, 1899
TURNBULL, WALLACE RUPERT.	Foreman of Experimental Room, General Electric Lamp Works; residence, 29 S. Arlington Ave., East Orange, New Jersey.	May 17, 1898
TYNG, FRANCIS E.	Manager, Eastern Engineering Co., 164 W. 27th St., New York; residence. Cranford, N. J.	Dec. 28, 1898
VAIL, THEO. N.	26 Cortlandt St., New York City.	April 15, 1884
VAN BUREN, GURDON C.	Electrical Expert, with Federal Instrument Co., 82 State St., Albany, N. Y.	Oct. 25, 1892
VANDEGRIFT, JAMES A.	Treasurer and Manager, The Colorado Lamp Co., 2051 California St., Denver, Col.	Nov. 24, 1891

Name.	Address.	Date of Election.
VAN DEVENTER, CHRISTOPHER	Stanley Electric M'f'g. Co., Pittsfield, Mass.	Feb. 17, 1897
VAN VLECK, JOHN FALCONER	Constructing Engineer, The Edison Electric and Illuminating Co. of New York; residence, Glenridge, N. J.	Aug. 5, 1896
VAN WYCK, PHILIP V. R., JR.	New York Te'ephone Co., 15 Dey St.; residence, Plainfield, N. J.	April 21, 1891
VARNEY, WILLIAM WESLEY	City Commissioner of Baltimore, office, City Hall; residence 712 N. Carey St., Baltimore, Md.	Nov. 21, 1894
VENABLE, WM. MAYO	The National Contracting Co., 11 Broadway, New York City.	Nov 30, 1897
VINTEN, ERNEST STILES	Foreman Knob. Dept. Sargent Co.; residence, 89 Pearl St., New Haven, Conn.	April 27, 1898
VOIT, DR. ERNST	Professor of Electricity, Technical University, Schwanthalerstrasse, Munchen, Germany.	Mar. 21, 1894
VOSMAER, ALEXANDER	Electrical. Mechanical, Chemical Engineer, Director Electrical Research Laboratory, Zijlweg 49, Haarlem, Holland.	Nov. 18, 1896
VREELAND, F. K.	Ass't Engineer, Crocker-Wheeler Co , residence, 228 Orange Road, Montclair, N. J.	Oct. 26, 1898
WAGNER, HERBERT A.	Gen. Supt., Missouri. Edison Electric Co., and also with Wagner Electric Mfg. Co., 415 Locust St., St. Louis, Mo.	Sept. 28, 1898
WALLACE, CHAS. F.	Engineer, Stone and Webster, 4 P. O. Square: residence, 286 Chestnut Ave., Boston, Mass.	Nov. 18, 1896
WALLACE, WILLIAM	[Address unknown.]	April 15, 1884
WALLER, CHAS. WAITE	Sales Agent, General Electric Co., Claus Spreckels B'ld'g, San Francisco, Cal.	Aug. 23, 1899
WARDLAW, GEORGE A.	[Address unknown.]	Jan. 17, 1894
WARNER, CHAS. H.	Consulting Electrical Engineer, 764 Rock St., Fall River, Mass.	Dec. 20, 1893
WARREN, ALDRED KENNEDY	Electrical Engineer, 120 Centre St., New York; residence 114 E. 17th St., New York City.	Nov. 20, 1895
WASON, CHAS. W.	President and Purchasing Agent, Cleveland, Painesville and Eastern R. R., Purchasing Agent. Akron, Bedford and Cleveland R. R., 616 Garfield Bldg., Cleveland, O.	May 19, 1891
WATERMAN, MARCUS B.	Assistant Electrician, Consolidated Telegraph and Electrical Subway Co.. 55 Duane St , New York City; residence. 177 Lefferts Place, Brooklyn, N. Y.	Feb. 15, 1899

Name.	Address.	Date of Election.
WATERS, EDWARD G.	General Electric Co., 44 Broad St., New York City.	Mar. 18, 1890
WEBB, HENRY STORRS	International Correspondence Schools; residence, 225 Jefferson Avenue, Scranton, Pa.	Nov. 20, 1895
WEBSTER, EDWIN S	Firm of Stone & Webster, 4 P. O. Sq., Boston, Mass.	April 21, 1891
WEISE, WILL M. T.	Manager, Weise Bros., Library Building, Davenport, Iowa.	Aug. 13. 1897
WELLES, FRANCIS R.	Manufacturer, 46 Avenue de Breteuil. Paris, France.	Sept. 6, 1887
WELLS, WALTER FARRINGTON	Supt 3rd Dist., Edison Electric Illuminating Co., 55 Duane St., residence, 71 East 92d St., New York, N. Y.	Apr. 26, 1899
WEST, JULIUS HENRIK	Engineer, Handjery St., 58 Friedenau, Berlin, Germany.	Sept. 20, 1893
WHITAKER, S. EDGAR	Superintendent and General Manager of the Portland and Yarmouth Electric Railway Co., 440 Congress St., residence; 221 Cumberland St., Portland, Me.	Aug. 5, 1896
WHITE, CHAS. G.	Public Schools Sup't, and Instructor in Physics and Chemistry, Lake Linden, Mich.	Sept. 23, 1896
WHITE, JAMES GILBERT	J. G. White & Co., Electrical Engineers and Contractors, 29 Broadway, New York City.	April 2, 1889
WHITING, ALLEN H.	Assistant Engineer, Riker Electric Vehicle Co., Elizabethport, N. J. residence, 320 Lexington Ave., New York City.	Nov. 18, 1896
WHITING, S. E.	Assistant in Electrical Dep't., Harvard University; residence, 11 Ware St., Cambridge, Mass.	May 16, 1899
WHITMORE, W. G.	Electrical Engineer, General Electric Co., Edison Building, Box 3067, New York City.	Mar. 18, 1890
WHITNEY, CLINTON EUGENE	Draughtsman with Geo. T. Hanchett. residence 61 W. 114th St., New York City.	Nov. 22, 1899
WHITNEY, HENRY M. [Life Member.]	81 Milk St., Boston, Mass.	July 12, 1887
WHITTED, THOS. BYRD	District Engineer, The General Electric Co., Denver, Col.	Mar. 22, 1899.
WIDDICOMBE, ROBERT A.	Engineer, Western Electric Co.: residence, 1653 Roscoe St., Chicago, Ill.	Apr. 26, 1899
WIEDERHOLD, OSCAR	Sup't. of Commercial Lighting Co., cor. Morris Ave. and New St., Newark, N. J.	Aug. 13, 1897
WIESE, GUSTAV ADOLPH	City Electrician of Alameda, 718 Haight Ave., Alameda, Cal.	Sept. 25, 1895
WIGHTMAN, MERLE J.	Electrical Engineer, The Staten Island Midland Railway Co., Room 102, Times Building, N. Y. City.	Mar. 5, 1889
WILEY, GEO. LOURIE	Manager, Standard Underground Cable Co., 56 Liberty St., New York, residence, Arlington, N. J.	Feb. 28, 1900

Name.	Address.	Date of Election.
WILEY, WALTER S.	Engineer, with the American Waterworks, 1107 No. 40th St.. Omaha, Neb.	April 18, 1894
WILEY, WM. H.	Scientific Expert, 43 E. 19th St., New York City.	Feb. 7, 1888
WILKES, C. M.,	Engineer. D. H. Burnham & Co., 1142 The Rookery, Chicago, Ill.	Nov. 22, 1899
WILLIAMS, ARTHUR	General Inspector, The Edison Electric Illuminating Co., cf New York; residence, 155 Linden Boulevard, Brooklyn, N. Y.	June 23, 1897
WILLIAMS, CHARLES JR.	Electrician, 1 Arlington Street, East Somerville, Mass.	April 15, 1884
WILLIAMS, GEO. HENRY	District Supt. The Edison & Swan United Electric Co., Ltd., 134 Royal Avenue; residence, Culmore, Glenburn Park, Belfast, Ireland.	Oct. 27, 1897
WILLIAMS, WILLIAM HENRY	Professor of Mechanical and Electrical Engineering. Montana State College, Bozeman, Mont.	Sept. 28, 1898
WILSON, CHESTER P.	Chief Engineer, The Milwaukee Electric Railway and Light Co., 451 Broadway, Milwaukee, Wis.	Sep. 25, 1895
WILSON, HOWARD S.	Superintendent Puebla Electric Light Co., Puebla, Mexico.	Aug. 23, 1899
WILSON, ROBERT M.	Faculty of Applied Science, McGill University; residence, 31 Esplanade Ave., Montreal, P. Q.	Jan. 25, 1899
WINAND, PAUL A. N.	Engineer and Supt., Schleicher, Schumm & Co., 3200 Arch St., Philadelphia, Pa.	June 20, 1894
WINCHESTER, SAMUEL B.	5 Laurel St., Holyoke, Mass.	May 15, 1894
WINFIELD, JAMES H.	Sup't Eastern Division, Nova Scotia Telephone, Ltd., New Glasgow, N. S.	May 17, 1898
WINSLOW, I. E.	The General Traction Company, Ltd., 35 Parliament Street, Westminster, London, Eng.	Nov. 12, 1889
WINTRINGHAM, J. P.	Theorist, 36 Pine St., Cable address, "Atlantic Scrip," New York City, and 153 Henry St., Brooklyn, N.Y.	May 7, 1889
WIRT, HERBERT C.	Engineer, Supply Department, General Electric Co., Schenectady, N. Y.	June 26, 1891
WISE, JOHN SHREEVE, JR.,	Electrician The Pa. Mfg. Light and Power Co.; residence, 2023 Mt. Vernon St., Philadelphia, Pa.	Feb. 15, 1899
WOLFF, FRANK A. JR.,	Professor of Physics and Electrical Engineering, Corcoran Scientific School. Columbian University, and in office, U. S. Standard Weights and Measures, Washington, D. C.	Dec. 27, 1899
WOOD, ARTHUR J.	Associate Editor, *Railroad Gazette*, 32 Park Place, New York City.	Dec. 28, 1898

Name.	Address.	Date of Election.
WOOD, FRED. W.	General Manager, Los Angeles Railway Co., Los Angeles, Cal.	May 17, 1898
WOODBRIDGE, J. E.	Editor *American Electrician*, 120 Liberty St., New York City.	Oct. 26, 1898
WOODWARD, W. C.	Electrical Engineer, Narragansett Electric Lighting Co., 60 Weybosset St., residence, 30 Cushing St , Providence, R. I.	Nov. 18, 1896
WOODWORTH, GEO. K	Assistant Examiner, U. S. Patent Office; residence, 1424 S St., N. W., Washington, D. C.	Feb. 17, 1897
WOOLF, ALBERT E.	Electrician and Inventor, The Electrozone Co , 415 Lexington Ave., New York City.	Sept. 16, 1890
WORSWICK, A. E.	Vice-President and Resident Engineer F. C. D., 3rd Calla de las Artes, Mexico City.	Sept. 20, 1893
WOTTON, JAMES A.	Manager Wotton Electric and M'f'g. Co. Box 543, Atlanta, Ga.	Oct. 27, 1897
WRAY, J. GLEN	Assistant Engineer, Chicago Telephone Co., 1651 Fletcher Ave., Chicago, Ill.	Sept. 20, 1893
WYBRO, HARRISON C.	Electrical Engineer, Wybro-Hendy Co , 38 Fremont St., San Francisco, Cal.	Dec. 18, 1895
YARNALL, VERNON H.	Superintendent of Construction, for Sprague Elevator Co., 52 Broadway, New York City.	May 16, 1893
YOUNG, CHARLES I.	Electrical Engineer, Westinghouse Elec. & Mfg. Co., Land Title Bldg., Philadelphia, Pa.	June 27, 1895
YSLAS, CARLOS	Electrical Engineer and General Manager, Compania Telefonica Nacional, Jalapa, Ver. Mexico.	Nov. 18, 1896
ZABEL, MAX W.	Draughtsman and Student of Patent Law with John A. Brown & Cragg, 1450 Manadnock Bg., residence, 454 North Ave., Chicago, Ill.	Jan. 24, 1900
ZAHM, A. WILFORD	Electrical Engineer and Supt., Manhattan Light, Heat and Power Co., Manhattan Building, St. Paul, Minn.	Nov. 23, 1898
ZALINSKI, EDMUND L.	Captain of Artillery, U. S. A., (retired), The Century, 7 West 43d St., New York City.	May 17, 1887
ZAPATA, J. M. (16)	Constructing Engineer, The Mexican General Electric Co., Apartado 403, Mexico City.	Feb. 28, 1900
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Ball, W. D., N. Y. Life B'ld'g
Barton, Enos M., 227 South Clinton St.
Boggs L. S, 1140 Monadnock
Brinckerhoff, H. M., 258 Franklin St.
Brown, C. L., 1309 Monadnock B'ld'g
Comstock, L. K., 227 So. Clinton St.
Crandall, Chester D., 227 S. Clinton St.
Daggett. R. B., Marquette B'ld'g
Damon, G. A., 1541 Marquette B'ld'g
de Khotinsky. Capt, A., 5526 Jefferson Ave.
Dommerque, F.J., Congress & Green Sts.
Dunbar, F. W., 234 La Salle St.
Duncan, Thomas, Grant Works.
Eddy, H. C., Lees Building
Etheridge, Locke, 1001 Monadnock
Frantzen, Arthur, 225 Dearborn St.
Goltz, Wm., 1504 Monadnock B'ld'g
Hartwell Arthur, 171 La Salle St.
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Hellick. C. G., 203 Washington St.
Hibbard, Angus S. 203 Washington St.
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McMeen, S. G., 1306 Ashland Block
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INDIANA.

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4

Indianapolis.—Bentley, M. H., 230 North Meridian St.
Green, F. C., 1710 Prospect St.
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Louisville.

Hubley, G. W., 8th and Greene Sts.
McLeod, Geo., 29th & High Sts.
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New Orleans.

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Carroll, Leigh, 708 Union St.
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MAINE.

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Portland.

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Baltimore.

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Boston.

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Bancroft, C. F., 14 Kilby St.
Berthold, V. M., 125 Milk St.
Blodgett, Geo. W., B. & A. R. R.
Blood, J. B., 22A Equitable B'ld'g
Brophy, Wm., 12 Old Court House.
Burleigh, Chas. B., 200 Summer St.
Cabot, F. E., 55 Kilby St.
Chase, H. A., 8 Congress St.
Childs, A. E., 23 Centre St.
Codman, J. S., 31 Milk St.
Coffin, Chas. A., 180 Summer St.
Craig, J. Hally, 49 Federal St.
Cross, Chas. R., Mass. Inst. Tech.
Davenport, Geo. W., 61 Ames B'ld'g
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Smith, W. L., Mass. Inst. of Tech.
Spaulding, H. C., 410 Exchange B'ld'g.
Stearns, C. K., 60 State St.
Stone, Charles A., 4 P. O. Square
Taintor, Giles, 125 Milk St.
Wallace, C. F., 4 P. O. Square
Webster, Edwin S., 4 P. O. Square
Whitney, Henry M., 81 Milk St.

46

Cambridge.

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Clark, W. E., 57 Brattle St.
Whiting, S. E., 11 Ware St.

4

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Chelsea.

Hall, F. A., 824 Broadway.

1

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Lynn.

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Fish, Walter C., " "
Hopkins, N. S., " "
Lemp, H. Jr., Gen'l Electric Co.
Thomson, Elihu, " "

6

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Natick.

Appleyard, A. E.
Gale, H. B.

2

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Pittsfield.

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Kelly, J. F., " "
Perrine, F. A. C., " "
Rushmore, D. B., " "
VanDeventer, C., " "

6

Springfield.

Anderson, H. S., United E. L. Co.
Hyde, Jerome W., Wason Building

2

Worcester.

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Latham, H. M., Am. Steel and Wire Co.
Smith, H. B., Polytechnic Inst.

3

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Lake Linden.—White, C. G.

Sault Ste Marie.—Kenan, W.R.Jr.

MINNESOTA.

Minneapolis.

Burch, E. P., 1210 Guaranty B'ld'g.
Flather, J. J., Univ. of Minn.
Pillsbury, C. L., Lumber Exchange.
Shephardson, G. D., Univ. of Minn.

4

St. Paul.

Simpson, J. M., Grass Twine Co.
Zahm, A. W., Manhattan B'ld'g

2

Willmar.—Johnson, A. C.

MISSOURI.

Columbia.—Shaw, H. B.

Kansas City.

Morgan, J. L., City Hall.
Weeks, E. R., National Bank of Kansas City Building

2

St. Louis.

Baldwin, J. C. T., 10th & Olive Sts.
Durant, Geo. F., Telephone B'ld'g
Garrels, W. L., 4531 West Pine Bouv.
Hessenbruch, G. S., 205 Union Station Terminal.
Humphrey, H. H., 706 Lincoln Trust Bg.
Layman, W. A., 2017 Locust St.
McRae, A. L., 306 Oriel B'ld'g
Randall, J. E., 1912 Olive St.
Roper, D. W., 19th & Gratiot Sts.
Schlosser, F. G., 411 No. 11th St.
Schwedtmann, F., 2017 Locust St.
Swope, Gerard, Security Building
Sykes, H. H., Telephone Building
Wagner, H. A., 415 Locust St.

14

MONTANA.

Bozeman.—Williams, W. H.

Canyon Ferry.—Gerry, M. H., Jr.,

Great Falls.—Morrow, John T.

NEBRASKA.

Lincoln.—Brooks, Morgan.

Omaha.

Pearson, F. J., 1510 Howard St.
Schurig. E. F., 306 City Hall
Wiley, W. S., 1107 N. 40th St.

3

NEVADA.

Virginia City.—Fielding, Frank E.

NEW HAMPSHIRE.

Manchester.

Clough, A. L., Box 114
Smith, J. Brodie, 142 Merrimack St.

2

NEW JERSEY.

Ampere.

Dunn, G. S., Crocker-Wheeler Co.
Henshaw, F. V., " "
Vreeland, F. K., " "
Wheeler, S. S., " "

4

Atlantic City.—Elmer, Wm., Jr.

Bloomfield.

Carichoff, E. R., Sprague Electric Co.
Rosenbusch, G. " "

2

Bridgeton.—Smith, Oberlin

Camden.—Harrington, Walter E.

East Orange.

Jackson, F. E., 61 So. Grove St.
Turnbull, W. R., 29 So. Arlington Ave.

2

Elizabeth.

Diehl, Philip, Diehl M'f'g Co.
Bennett, E. H., Jr., Singer M'f'g Co.
Granbery, J. H. (Elmora Station)
Miller, H. S., Diehl M'f'g Co.
Riker, A. L., Riker Elec. Vehicle Co.
Whiting, A. H., " "

6

Harrison.

Howell, J. W.
Howell, Wilson S.
Marshall. J. T.
Page, A. D.

4

Hoboken.

Cuntz, Johannes H., 325 Hudson St.
Denton, J. E., Stevens Institute
Ganz, A. F., " "
Geyer, Wm. E., " "
Morton, Henry " "

5

Jersey City.

Ockershausen, H. A.
Rushmore, S. W., 24 Morris St.

2

Newark.

Anthony, Watson G., 32½ Webster St.
Bosch, Adam, Fire Alarm Telegraph.
Colby, Edward A., Lock Box 113
Flack, J. Day, 46 Bridge St.
Hammer, E. W., 46 2d Ave.
Moore, D. McF., 52 Lawrence St.
Weston, Edward, 114 William St.
Wiederhold, O., Morris Ave. & New

8

Orange.

Edison, Thomas A.
Upton, F. R.

2

Plainfield.

McClurg, W. A., 207 Madison Ave.
Waldo, Leonard, 520 Stelle Ave.

2

Port Oram.—Klinck, J. H.

Princeton.—Brackett, C. F.

Rahway.—Buys, Albert

Roselle.—Colvin, F. R.

Rutherford.

Petty, Walter M.
Schwabe, W. P.

2

Somerville.—Tait, F. M.

South Orange.—Delany, P. B.

Trenton.

Horn, H. J., 36 W. State St.
Newbury, F. J., Roeblings Co.
Roebling, F. W., Roeblings Co.

3

Westfield.

Berresford, A. H.
Foote, Thos. H.
Mansfield, R. H.

3

NEW MEXICO.

Mesilla Park.—Brady, F. W.

NEW YORK.

Albany.

Judson, W. P., State House.
McElroy, James F., 131 Lake Ave.
Miller, Wm. C., 3 South Hawk St.
Van Buren, Gurdon C., 82 State St.

4

Auburn.—Case, W. E.

Belmont.—Gorton, Charles

Bronxville.

Carpenter, C. E.
Leonard, H. Ward

2

Brooklyn.

Barstow, W. S., 360 Pearl St.
Benoliel. S. D., Adelphi College
Broich, Jos., 1622 8th Ave.
Chapman, A. W., 160 Hicks St.
Dexter, F. H., 268 23d St.
DuBois, T. D. 2195 Pitkins Ave.
Leitch, H. W., 373 Madison St.
Martin, J., Navy Yard.
Mosscrop, W. A., 47 Brevoort Pl.
Ormsbee, A. F., 81 Willoughby St.
Peck, E. F., 187 Montague St.
Peckham. W. C., 406 Classon Ave.
Reilly, John C., 81 Willoughby St.
Rice, A. L., Pratt Institute
Sargent, W. D., 81 Willoughby St.
See, A. B., 116 Front St.
Shaw, A. N., 116 Front St.
Sheldon, Samuel, Polytech. Institute.
Wolcott, T., 329 Clinton St.

19

Buffalo.

Foster, H. A., 682 Ellicott Sq.
Frenyear, T. C., 782 " "
Gifford, C. E., 231 Hudson St.
Haskins, C. H., 70 Linwood Ave.
Huntley, C. R., 40 Court St.
McCarthy, E. D., 45 No. Division St.
Meadows, H. G., 109 White B'ld'g.
Offinger, M. H., 304 Pine St.
Perkins. Frank C., 126 Erie Co. Bank.
Plumb. Chas., 70 West Swan St.
Pope, H. W., 14 W. Seneca St.
Sowers. D. W., 240 W. Utica St.
Stott, H. G., 40 Court St. 13

Carthage.—Lanphear, B. S.

Elmira.

Cheney. F. A. Maple Ave.
Uebelacker, C. F., Munic Improv'nt Co.
Wolverton, B. C., N.Y. & Pa. T. & T. Co.

3

Flushing.—Phillips, L. A.

Ithaca.

Bedell, Fred. Dr., 117 E. Buffalo St.
Bergholtz, H., Ithaca Street Ry. Co.
Hardy, C. E., 804 E Seneca St.
Lohmann, R. W., 102 West Ave.
McClenathen. R., Box 476
Moody, V. D., 215 Dryden Road.
Nichols,, E. L., Cornell University.
Ryan, H. J., " " S

Larchmont.—Neilson, John
Mamaroneck.—Farnsworth, A. J.
New Brighton.—Libby, S. B.
Newburgh.—Hewitt, C. E.

New York City.

Abbott, Henry, 9 Maiden Lane
Adae, C. F., 67 Madison Ave.
Adams, E. K., 455 Madison Ave.
Agnew, C. R., 18 William St.
Albright, H. F., 57 Bethune St.
Alexander, Harry, 25 W. 33d St.
Andrews, W. C. 120 Liberty St.
Anthony, W. A., Cooper Union
Archbold, W. K., 120 Broadway
Archer, Geo. F., 31 Burling Slip
Ashley, F. M., 95 Liberty St.
Atkins, H. B., 22 William St.
Atwood, G. F., 95 Liberty St.
Auerbacher, L. J., 39 Cortlandt St.
Austin, S. B., 32 Gold St.
Baillard, E. V., Fox Building.
Baldwin, A. de V., 39 Cortlandt St.
Bangs, C. R. 15 Dey St.
Banks, W. C., 594 Broadway
Baron, Max D., 25 W. 33rd St.
Batchelor, C., 44 Broad St.
Bates, F. C., 44 Broad St.
Bates, J. H., 66 Maiden Lane
Bates, P. A., 39 Cortlandt St.
Baylis, R. N., 99 Cedar St.
Bell, O. A., 57 Bethune
Bellman, J. J., 26 Cortlandt St.
Bennett, J. C., 44 Broad St.
Bethell, U. N., 15 Dey St.
Betts, H. D., 141 Broadway
Bijur, Jos., 34 Nassau St.
Birdsall, E. T., 26 Cortlandt St.
Black, C. N., 149 Broadway.
Black, H. D., 39 Cortlandt
Blackall, F. S., 39 Cortlandt St.
Blake, Henry W., 120 Liberty St.
Blake, T. W., 410 Bleecker St.
Bliss. W. L.. 128 Front St.
Bonynge, Paul, 141 Broadway.
Bogue, Chas. J., 206 Centre St.
Bohm, Ludwig K., 320 Broadway.
Bourne, Frank, 26 Cortlandt St.
Bradley, C. S., 44 Broad St.
Brixey, W. R., 203 Broadway.
Brown, Alfred S., 195 Broadway
Brown, J. Stanford, 1 Broadway
Buckingham, Chas. L., 195 Broadway

New York City.—Continued.

Bunce, Theo. D. Jr., 239 E. 27th St.
Burnett, Douglass, 55 Duane St.
Burroughs, H. S., 527 W. 34th St.
Burton, Paul G., 57 Bethune St.
Burton, W. C., 29 Broadway
Byrns, R. A., 20 Broad St.
Cabot, J. A., 124 W. 127th St.
Caldwell, Edw., 150 Nassau St.
Canfield, M. E., 57 Bethune St.
Carty. J. J., 15 Dey St.
Chamberlain, J. C., 1 W. 81 St.
Chandler, C. F., Columbia Univ.
Clark, C. M., 42 E. 23d St.
Clark, Ernest P., 19th St. & 6th Ave.
Clark, Le Roy, Jr., 229 W. 28th St.
Clark, W. J., 44 Broad St.
Clarke, Charles L., 31 Nassau St.
Coho, H. B., 149 Broadway
Collett. S. D., 136 Liberty St.
Cornell, C. L., 136 Liberty St.
Compton, A. G., 17 Lexington Ave.
Criggal, J. E., 463 West St.
Crocker, Francis B., Columbia Univ.
Cushing, H. C., Jr.. 39 Cortlandt St.
Cuttriss, Chas., 20 Broad St.
Dana, R. K., 240 W. 74th St.
Davidson, E. C., 141 Broadway
Davis, Charles H., 99 Cedar St.
Davis, Joseph P., 113 W. 38th St.
Davis, Minor M., 253 Broadway
Decker, E. P., 26 Cortlandt St.
Dey, Harvey E., 711 E. 136th St.
Dickerson. E. N., 141 Broadway
Doherty, H. L., 40 Wall St.
Doremus, C. A., 59 W. 51st St.
Dressler, Chas. E., 17 Lexington Ave.
Duncan, J. D. E., 100 Broadway.
Duncan, Louis, 71 Broadway
Dunn, C. E., 1029 Park Row B'ld'g.
Durant. Edward, Ward's Island.
Dyer, R. N., 31 Nassau St.
Edwards, C. V., 220 Broadway
Field, C. J., 1123 Broadway
Fliess, R. A., 201 W. 55th St.
Floy, Henry, 220 Broadway
Forbes, Francis, 32 Nassau St.
Ford, A. H., 463 West St.
Ford, F. R., 149 Broadway
Frank, G. W., Jr., 29 Brodway
Frost, J. W., 335 Broadwaay
Gallaher, E. B., 120 Liberty St.
Gallatin, A. R., 58 W. 55th St.
Gardanier, George W., 195 Broadway.
Gherardi, B. Jr., 15 Dey St.
Gibson, G. H., 220 Broadway
Gladstone, J. W., 110 110 E. 23rd St.
Goldmark, Chas. J., 29 Broadway
Gordon, Reginald, Columbia Univ.
Griffen, J. D., 60 Broadway.
Griffin, E., 44 Broad St.
Guy, Geo. H., 120 Liberty St.
Hadaway, W. S. Jr. 107 Liberty St.

New York City.—Continued.

Hall, Edw. J., 15 Dey St.
Hall, J. P., 22 Thames St.
Hallberg, J. H., 572 First Ave.
Hamilton, Geo. A., 463 West St.
Hamerschlag, A. A., 100 Maiden Lane.
Hammer, W. J., 922 Havemeyer Bg.
Hanchett, Geo. T., 123 Liberty St.
Harding, H. McL. 20 Broad St.
Hathaway, J. D., Jr., 463 West St.
Hatzel, J. C., 114 Fifth Ave.
Hayes, Harry E., 22 Thames St.
Hedenberg, W. L., 136 Liberty St.
Henderson, Alex., 527 W. 34th St.
Herzog, Dr. F. Benedict, 51 W. 24th St.
Higgins, Edward E., 120 Liberty St.
Hildburgh, W. L., Hotel Normandie
Hill, George, 150 5th Ave.
Hill, G. Henry, 527 W. 34th St.
Hoffman, B., 15 Dey St.
Holbrow, H. L., 15 Dey St.
Holmes, Franklin S., 108 Fulton St.
Howson, Hubert, 38 Park Row
Hubbard, A. S., 25 W. 33d St.
Hubbard, W. C., 11 Broadway.
Hunt, A. L., 203 Broadway
Hutchinson, Cary T., 71 Broadway
Hyde, J. E. H., 120 Broadway.
Idell, Frank E., Havemeyer Building.
Insull, M. J., 572 1st Ave.
Jaeger, C. L., 132 Mulberry St.
Jannus, F., 149 Broadway
Jenks, W. J., 120 Broadway
Johnston, T. J., 66 Broadway.
Jones, Francis W., 253 Broadway
Keefer, E. S., 463 West St.
Ker, W. W., 36 Stuyvesant St.
King, V. C., Jr., 517 West St.
Kinsley, Carl, Governor's Island.
Kinsman, F. E., 26 Cortlandt St.
Knowles, E. R., 136 Libeyty St.
Knox. C. E., 150 Nassau St.
Knudson, A. A., 32 Nassau St.
Lamb, Richard, 136 Liberty St.
Langton, Jno., 72 Trinity Pl.
Lanman, Wm. H., 120 Broadway
Lardner, H. A., 29 Broadway.
La Roche, F. A., 652 Hudson St.
Lawrence, W. H., 49 W. 26th St.
Ledoux, A. R., 99 John St.
Leslie, E. A., 57 Duane St.
Levy, Arthur B., 810 Lexington Ave.
Lieb, J. W., Jr., 57 Duane St.
Livingston, J. Jr., 13 Park Row
Lloyd, Robert McA., 100 Broadway
Loewenthal, M., World B'ld'g.
Louis, O. T., 340 E. 119th St.
Lovejoy, D. R., 44 Broad St.
Lozier, R. T. E., 220 Broadway
Lundell, Robert, 527 W. 34th St.
Lundie, John, 52 Broadway
Luquer, T. T. P., 15 Dey St.
Lyman, C. W., 30 Broad St.

New York City.—Continued.

MacGregor, W. H., 136 Liberty St.
Mackie, C. P., 30 Broad St.
Magnus, Benj., 22 E. 111th St.
Mahoney, J. J., 44 Broad St.
Mailloux, C. O., 150 Nassau St.
Mansfield, A. N., 22 Thames St.
Marks, L. B., 689 Broadway
Martin, F., 56 Liberty St.
Martin T. Commerford, 120 Liberty St.
Marvin, H. N., 841 Broadway.
Maver, William . Jr., 120 Liberty St.
Mayer, M. M., 2369 2d Ave.
McClure, W. J., 259 W. 52d St.
McLain, R. C., 21 Park Row.
Merrill, E. A., 26 Cortlandt St.
Mershon, R. D., 120 Broadway
Meyer, Julius, 55 Broadway
Millis, Maj. John, 29 Whitehall St.
Molé, H. E., 29 Broadway
Mora, M. L. 44 Broad St.
Morley, E. L., 114 5th Ave.
Moses, Otto A., 1037 Fifth Ave.
Moses, P. R., 35 Nassau St.
Mullin, E. H., 44 Broad St.
Murphy, J. McL., 116 Nassau St.
Muschenheim, F. A., 463 West St.
Nimis, A. A., 204 E. 86th St.
Noll, Augustus, 8 E. 17th St.
Osterberg, Max, 11 Broadway
Paine, F. P. H., 120 Broadway
Parker, H. C., Columbia Univ.
Parmly, C. Howard, 17 Lexington Ave.
Parsell, H. V. Jr., 129 W. 31st St.
Pattison, Frank A. 141 Broadway
Pearson, F. S., 621 Broadway
Pedersen, F. M. 17 Lexington Ave.
Pfund, Richard, 601 W. 169th St.
Pickernell, F. A., 22 Thames St.
Poole, Cecil P., 120 Liberty St.
Pope, Ralph W., 26 Cortlandt St.
Porter, H. H., Jr., 31 Nassau St.
Price, C. W., 41 Park Row
Prince, J. L., 57 Duane St.
Proctor, T. L., 39 Cortlandt St.
Pupin, Michael I., Columbia Univ.
Reber, Samuel, Governor's Island.
Reckenzaun, F., 44 Pine St.
Reed, H. A., 420 E. 25th St.
Reed, H. D., 420 E. 25th St.
Reid, E. S., 17 Times Building
Reid, Thorburn, 120 Liberty St.
Rennard, J. C., 15 Dey St.
Rice, Calvin W., 55 Duane St.
Ries, E. E., 346 Broadway
Ripley, W. H., 24 Murray St.
Roberson, O. R., 195 Broadway
Robinson, F. G., 621 Broadway
Roller, F. W., 203 Broadway
Rosenbaum, Wm. A., Times B'd'g
Rosenberg, E. M., 138 W. 85th St.
Rouquette, W. F. B., 47 Dey St.
Ryerson, W. N., 332 W. 56th St.

New York City.—Continued.

Sanborn, F. N., 29 Wall St.
Sanderson, E. N., 31 Nassau St.
Saxelby, F., 220 Broadway.
Scheffler, F. A., 9 Dey St.
Schreiter, Heinr., 106 Fulton St.,
Schum, C. H., 652 Hudson St.
Scudder, H. Jr., 21 E. 22d St.
Serrell, Lemuel Wm. 99 Cedar St.
Sever, Geo. F., Columbia Univer.
Simpson, A. B., 54 M. Lane
Sinclair, H. A., 35 South William St.
Skirrow, J. F., 253 Broadway
Slade, A. J., 289 4th Ave.
Slater, F. R., 32 Park Place
Smith, J. Elliott, 122 W. 73d St.
Smith Jesse M., 218 Broadway
Smith, T. Jarrard, 98 Fulton St.
Sprague, Frank J., 527 W. 34th St.
Stadelman, W. A., 26 Cortlandt St.
Stewart, W. M., 30 Gold St.
Stieringer, Luther, 120 Liberty St.
Stockbridge, Geo. H., 120 Broadway
Stout, J. S., Jr., 55 Duane St.
Strauss, H. A., 111 E. 61st St.
Stutz, C. C., 527 W. 34th St.
Swann, J. J., 26 Cortlandt St.
Taltavall, Thos. R., 120 Liberty St.
Taylor, I. A., 120 Liberty St.
Terry, Chas. A., 120 Broadway
Tesla, Nikola, 46 E. Houston St,
Thomas, R. McK. 141 Broadway
Thompson, Edward P., 81 Fulton St.
Thurber, H. F., 15 Dey St.
Torchio, P., 53 Duane St.
Townsend. Henry C., 141 Broadway
Townsend, Fitzhugh, Columbia Univ.
Treadwell, A., 100 Broadway
Tyng, F. E., 164 W. 27th St.
Vail, Theo. N., 26 Cortlandt St.
Vansize, William B., 253 Broadway
Van Vleck, J. F., 57 Duane St.
Van Wyck, P. V. R., Jr., 15 Dey St.
Venable, W. M., 11 Broadway
Waddell, M., 72 Trinity Pl.
Warren, A. K., 120 Centre St.
Waterman, F. N., 120 Broadway
Waterman, M. B., 55 Duane St.
Waters, E. G., 44 Broad St.
Weaver, W. D., 120 Liberty St.
Webb, Herbert Laws, 15 Dey St.
Wells, W. F., 55 Duane St.
Wetzler, Joseph, 240 W. 23rd St.
White, J. G., 29 Broadway
Whitmore, W. G., 44 Broad St.
Whitney, C. E., 123 Liberty St.
Wightman, M. J., 102 Times B'ld'g
Wiener, A. E., 240 W. 23rd St.
Wiley, Geo. L., 56 Liberty St.
Wiley, Wm. H., 43 E. 19th St.
Williams, A. 57 Duane St.
Willyoung, E. G., 82 Fulton St.
Wilson, C. H., 26 Cortlandt St.
Wilson, Fremont, 66 Maiden Lane

New York City.—Continued.

Wintringham, J. P., 36 Pine St.
Wood. A. J.. 32 Park Place
Woodbridge, J. E., 120 Liberty St.
Woolf, Albert 415 Lexington Ave.
Yarnall, V. H., 52 Broadway
Young, C. G., 29 Broadway.
Zalinski, Capt. E. L., 7 N. 43d St.

303

Official Stenographer.

Ryan, R. W., Rm. 178 P. O. B'ld'g

Niagara Falls.

Acheson, E. G., Carborundum Co.
Edmands, I. R., Union Carbide Co.
Lincoln, P. M., Cataract Const. Co.
Price, E. F., Union Carbide Co.
Stillwell, L. B., N. F. Power Co.

5

Ogdensburg.—Jones, M. E.
Pelham Manor.—Gilliland, E. T.
Potsdam.—Dates, H. B.
Rhinecliff.—Philbrick, B, W.

Rochester.

Barnes, C. R.
Redman, G. A.

2

Saratoga Springs.—Dunston, R.E.

Schenectady.

Andrews, W. S.,	General Electric Co.
Armstrong, A. H.,	" " "
Badeau, I. F.,	" " "
Berg, E. J.,	" " "
Berg, Eskil.	" " "
Blackwell, F. O.,	" " "
Boyles, T. D.,	" " "
Buck, H. W., 107 Union St.	
Davis, A. G.,	General Electric Co.
Davis, W. J. Jr.,	" " "
Dempster, Thos.,	" " "
Emmet, W. L. R.,	" " "
Ely, W. G. Jr.,	" " "
Ekstrom, Axel,	" " "
Eyre, M. K. ℅ W. L. R Emmet,	" " "
Hewlett, Edw. M.,	" " "
Kellogg, J. W.	" " "
Knox, S. L. G.,	" " "
Lovejoy, J. R.,	" " "
Middleton, A. C.,	" " "
Potter, W. B.,	" " "
Powelson, W. V. N.	" " "
Read, R. H.,	" " "
Reed. W. W.,	" " "
Reist, H. G.,	" " "
Rice, E. Wilbur, Jr.,	" " "
Rohrer, Albert, L ,	" " "
Sargent, H. R.,	" " "
Stebbins, Theodore	" " "
Steinmetz, C. P.,	" " "
Wirt, H. C.,	" " "

31

Syracuse.

Brady, Paul T.
Cahoon, J. B., 729 Crouse Ave.
Emerick, L. W., The Kenyon
Land, Frank, 220 Green St.
Nicholson, W. W., Telephone B'ld,g
Noxon, C. P. L., 500 E. Water St.
6

Tarrytown.—Crehore, A. C.

Tompkinsville.—Gregg, T. H.

Troy.—Bernard, Edgar G., 450 Fulton St.

Whitestone.—Uhlenhaut, F. Jr.

Yonkers.

Hull, S. P., N. Y. C. & H. R. R. R.
Ihlder, John D., Otis Electric Co.
James, H. D., 100 Buenos Vista Ave.
Scidmore, F. L., 21 Highland Ave.
4

NORTH CAROLINA.

Charlotte.—Sampson, F. D.

OHIO.

Akron.

Pomeroy, W. D.
Shaw, E. C.
2

Cincinnati.

Baldwin, B. L., 73 Perin B'ld'g
Bogen, L. E., Univ. of Cincinnati.
Creaghead, Thos. J., 802 Plum St,
French, Thos. Jr., 713 Ridgeway Ave.
Lilley, L. G., Cor. 3d & Walnut
Merrill, J. L., 420 W. 4th St.
Reno, C. S., 620 Baymiller St.
Rodgers, H. S., 420 W. 4th St.
White, W. F., 220 W. 8th St.
9

Cleveland.

Brush, Chas. F., 453 The Arcade.
Canfield, Milton C., 18 Clinton St.
Cowles, Alfred H., 361 Arcade.
Hoag, G. M., 113 City Hall.
Jackson, E. D., 905 Electric B'ld'g.
Lindsay, Robert, 771 Cuyahoga B'ld'g
Roberts, E. P., Electric Building.
Sperry, E. A., 855 Case Ave.
Wason, Chas. W., 2069 Euclid Ave.
9

Columbus.

Caldwell, F. C., State University.
Fish, F. A., " "
Johnson, H. S., 70 Jefferson Ave.
Thomas, B. F., State University
4

Dayton.

Thresher, A. A.

East Liverpool.—Healy, L. W.

Hamilton.—Cornell, J. B.

Piqua.

Lorimer, G. W.
Lorimer, J. H.
2

Salem.—Davis, Delamore L.

Steubenville.—Flood, J. F.

Toledo.—Bechtel, E. J.

OREGON.

Oregon City.—Cheney, W. C.

Portland.

Mitchell, Sidney Z., Fleischner B'ld'g
Shock, T. A. W.
2

Salem.—Anson, F. R.

PENNSYLVANIA.

Allegheny.

Fessenden, R. A., Univ. W. Pa.
Smith, F. S.
2

Altoona.

Dudley, C. B.
1

Bethlehem.—Lattig, J. W.

Braddock.—Maccoun, A. E.

Duquesne.—Friedlander E.

East Pittsburg.—Corey, F. B.

Erie.—Behrend, B. A., Box, 604.

Munhall.—Dinkey, A. C.

Phœnixville.—Perot, L. Knowles.

Philadelphia.

Biddle, J. G., Drexel B'ld'g
Billberg, C. O. C., 3300 Arch St.
Blanchard, C. M., 1127 Betz B'ld'g.
Blizard, C., 19th St., & Allegheny Ave.
Bolan, T. V., 509 Arch St.
Braddell, Alfred E., 316 Walnut St.
Bragg, Chas. A., Land Title B'ld'g
Clement, E. E., 1205 Girard B'ld'g.
Cumner, A. B., 251 S. 12th St.
Darlington, F. W., 931 Drexel B'ld'g.
Degen, Lewis, 1414 Chestnut St.
Drysdale, W. A., Hale B'ld'g
Eglin, W. C. L., Cor. 10th & Sansom.
Entz, J. B., 19th St. & Allegheny Ave.
Firth, W. E., Nicetown
Gharky, W.D., 1205 Stephen Girard Bg.

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Hartman, H. T., 1406 Land Title Bg.
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Hodge, W. B., 707 Spruce St.
Hommel, L., 1225 Betz B'ld'g
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Hunter, Rudolph M., 926 Walnut St.
Keller, E. R., 727 Reading Terminal
Kennelly, A. E., 1203 Crozer B'ld'g
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Scott, W. M., 108 W. Johnson
Smith, T. Carpenter, 650 Drexel B'ld'g
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Spencer, Theo., 406 Market St.
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Toerring, C. J., 1035 Ridge Ave.
Vail, J. H., 10th & Sansom
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Wise, J. S., Jr., 2023 Mt. Vernon St.
Young, C. I., Land Title B'ld'g

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3

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Spartanburg.—Knox, F. H.

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3

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Mix. Edgar W., 12 Boul. des Invalides.
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Otten, Dr. J. D., Van Baerlestraat 10
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Wallace, Wm.
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